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Master thesis presented to the University of Aveiro (UA) to fullfil the requirements for the Master degree in Environmental Studies (Joint European Master Programm in Environmental Studies – JEMES). It was done under the scientific supervision of Doctor Ana Isabel Miranda, Professor of the Department of Environment and Planning of the UA and co-supervision of Doctor Wolfgang Calmano, Professor of the Institute of Environmental Technology and Energy Economy of the Technische Universitat Hamburg-Harburg (TUHH).

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Keywords

Vehicle emissions, Emission inventory, Querétaro, IVE model

Abstract

Air pollution has been one of the priorities issues in the environmental awareness, especially in cities from developing countries. Transport sector has an important contribution to the urban air quality degradation in these countries. Hence the importance to develop traffic emission inventories in order to allow the identification and quantification of atmospheric pollutant emissions in a defined area. The aim of this work is to develop a traffic emission inventory for the city of Querétaro, Mexico, using two different approaches (top-down and bottom-up) and to compare the results obtained from using both methodologies. Vehicle emissions from top-down inventory for the state of Querétaro show an increase compared to vehicle emissions reported in the 1999 Mexican National Emission Inventory due to the accelerated growth and development of the city of Querétaro. Emissions from the municipalities located in the south of the state of Querétaro are higher than in the rest of the municipalities, probably due to the higher number of highways and roads existing in this area. Vehicle emissions from bottom-up inventory using IVE model and considering different type of roads show that arterial roads are the main contributors of emission due to vehicle activity, followed by highways, second arterial roads, and local roads. The comparison of the two methodologies shows that CO emissions from bottom-up inventory are higher than CO emissions from top-down inventory. One of the possible reasons for having this behaviour is due to the default parameters used by IVE model which might cause an overestimation of CO emissions. In order to have a better understanding of this difference further analysis of the default parameters used by IVE model should be considered. Local emission factors and traffic measurements are strongly recommended to be used in IVE model in order to improve vehicle emission estimations.

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1. Introduction

Nowadays the world is facing a challenge regarding environmental sustainability. It is well known that we live in a dynamic world with constant changes in the environment as well as in our society. These changes take place due to population growth, increment in urban and industrial spaces, social, economic, and political processes that influence our lifestyle, and in some cases these bring as consequence a wrong management of the environment. One of these consequences is air pollution, which today is one of the main concerns in the developed and developing world.

According to the United Nations 1979 Convention on Long-range Transboundary Air Pollution, on its First Article air pollution is defined as “the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment” (UNECE, 1979). Presently not only the human introduction of substances in the atmosphere is considered as an air pollution activity, but also a particular concern is given to the natural emissions that can impair the environment. Atmospheric emissions can occur in a natural way due to fires, volcanic eruptions, geysers, sulfur springs, or erosion caused by wind, and they have been occurring since centuries ago. Another way atmospheric emissions can occur is due to anthropogenic activities mainly as a result from burning of fossil fuels, waste, and chemicals (Jacobson, 2005).

With the emerging of industrialization anthropogenic emissions increased in a significant amount, and today urbanization is one of the main factors that cause these emissions to continue increasing. According to the United Nations Population Fund (UNFPA) State of Population Report 2007, population in urban areas will increase up to 4.9 billion by 2030, bringing as consequence not only a decrease in air quality, but also health problems to the population (Jacobson, 2005).

At the present time the transport sector has an important contribution to the urban air quality degradation (Alonso et al, 2010). The continued use of motor vehicles has led to an increase in atmospheric emissions as the result from the combustion of fossil fuels, emitting pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds

(VOC), and particulate matter (PM), which are in direct contact to human receptors (Smit, 2006). In highly urbanized areas the contribution of road traffic emissions is considered to be significant, especially for CO, VOC, and NOx, as shown in figure 1.

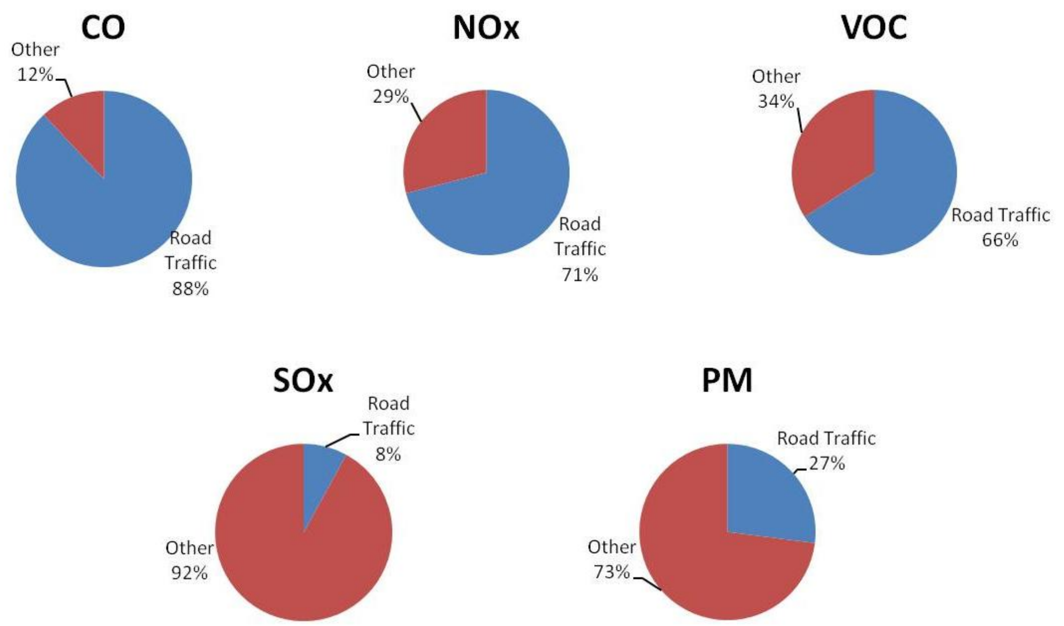

Figure 1. Contribution of road traffic emissions in urban areas (Smit, 2006).

Even though urbanization is important for economic, social, and environmental issues, if it happens in cities less developed that may not have the strength to lead with it, then a greater problem will take place. In the last decades air pollution has been one of the priorities issues in the environmental awareness, especially in cities from developing countries that have experienced a dramatic growth. In fact, the situation in developing countries regarding air pollution is not so different from the situation experienced before in the developed ones (Osses, 2005). Some studies carried out by The World Bank in Latin America and Caribbean Region have shown that transport sector contributes in almost a 70% of the atmospheric emissions in cities from Latin America (TWB, 2006) and it is expected a similar behavior in some other cities from the developing world. Statistics in Latin America show that vehicle fleet has increased dramatically, about 42% in Mexico, 37% in Chile and 13% in Brazil in the last decade (Lacasaña et al., 1999).

The main problem regarding mobile sources in these countries is not only the increase in their vehicle fleet, but also that most of these vehicles are badly maintained releasing higher amounts of pollutants to the atmosphere; for instance in Latin America a significant amount of NO_2 and PM emissions are released by mobile sources particularly in cities where vehicle fleet is old and diesel fuel is used (Baldasano et al., 2003). Another problem that can be addressed is the lack of quality data to develop studies to identify and quantify atmospheric emissions. This data can be traffic activity data, detailed surveys about vehicle fleet, traffic patterns, and street configuration which are needed to develop accurate emission inventories. (Osses, 2005; Alonso et al., 2010)

Hence, a first challenge is to develop traffic emission inventories for these countries; unfortunately until now little has been done in most of these regions. According to studies developed by The World Bank (2006) there are very few countries in Latin America that have available emission inventories. In these studies different countries in Latin America were evaluated according to the existence of emission inventories in their main urban centers, the results are shown in figure 2.

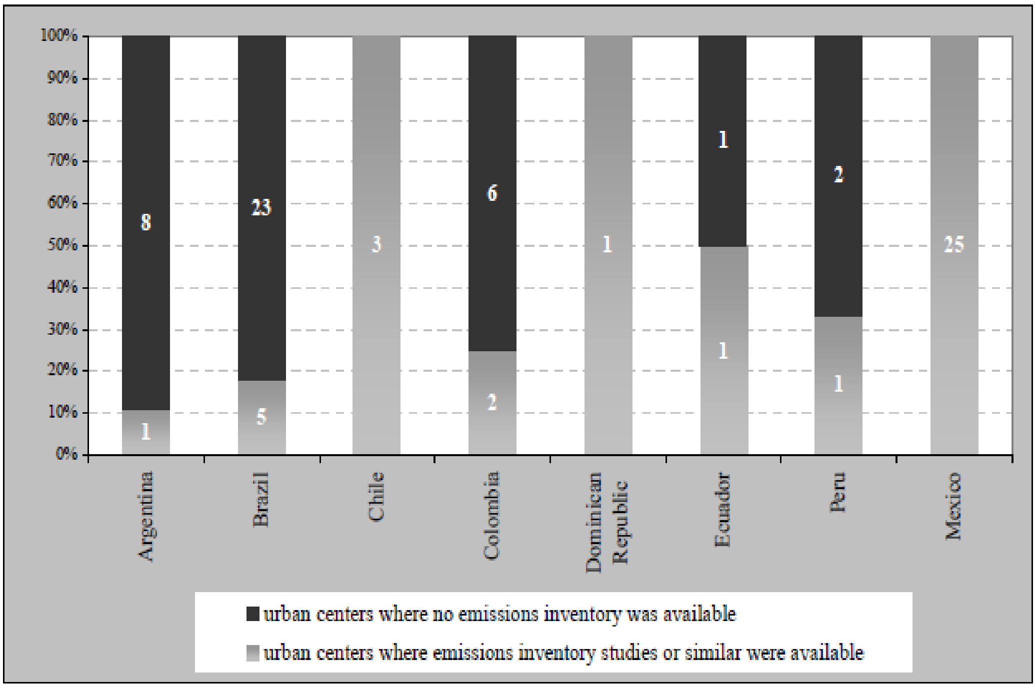

Figure 2. Available Emission inventories for cities in Latin America countries (TWB, 2006).

It was found that in most of these countries the percentage of the evaluated cities without available emission inventories is higher than the ones with available inventories; the numbers in the columns represent the cities evaluated in each country with and without available emission inventories. For Chile, Dominican Republic and Mexico it was found that all the urban centers which were evaluated had available emission inventories, but still the number of cities evaluated is low compared to the amount of cities existing in these countries, and most of them lack of emission inventories. This situation can be improved by extrapolating the available data to cities in similar conditions and later when it can be possible enhance the emission inventories with real data from these areas.

Even though there is still work to do, some efforts have been made to improve air quality in developing countries from Latin America and Caribbean region. Brazil and Argentina are developing national and regional emission inventories, Chile has developed its Air Pollution Control Plan defining global policies and actions to decrease emissions from mobile and other sources, and Mexico has its vehicular emission control program, which includes the introduction of oxygenized gasoline, and is releasing a program against atmospheric pollution (PICCA) (Alonso et al., 2010; Lacasaña et al., 1999). Some of these efforts have been applied mainly in big cities, but the challenge must expand to smaller cities which continue growing without efficient air pollution control measures and which also contribute to the overall atmospheric emissions. Mid-sized cities in developing countries are compact cities with about 100,000 to 1,000,000 inhabitant, and with an important road network. There are numerous cities in Latin America with such characteristics. The main problem with these cities is the lack of resources to develop traffic models, but they are still good choices for applying simple methodologies for developing emission inventories (Osses de Eicker et al., 2008).

The aim of this thesis is to provide an emission inventory focused in traffic emissions for a mid-sized city in Mexico, which may be used as background information and approach for future atmospheric emission studies in developing countries. The main objectives of this work are the followings:

1) Develop a traffic emission inventory for the city of Querétaro, Mexico, using two different approaches (top-down and bottom-up);
2) Compare the results from the different methodologies used in this study.

After this introductory part, the thesis presents a brief overview of traffic road emissions. The third chapter introduces traffic emission inventories and the different methodologies used for their development. The fourth chapter includes the characterization of the study area, the city of Querétaro, and the description of the used methodologies. Results obtained are presented in chapter 5, and finally the conclusions of this study are provided in chapter 6.

2. Traffic road emissions

Anthropogenic activities such as fossil fuel consumption, energy production, industrial activities, and transportation, among others have played an important role in the increasing contribution of atmospheric emissions. These emissions differ from developed and developing countries, as shown in Figure 3.

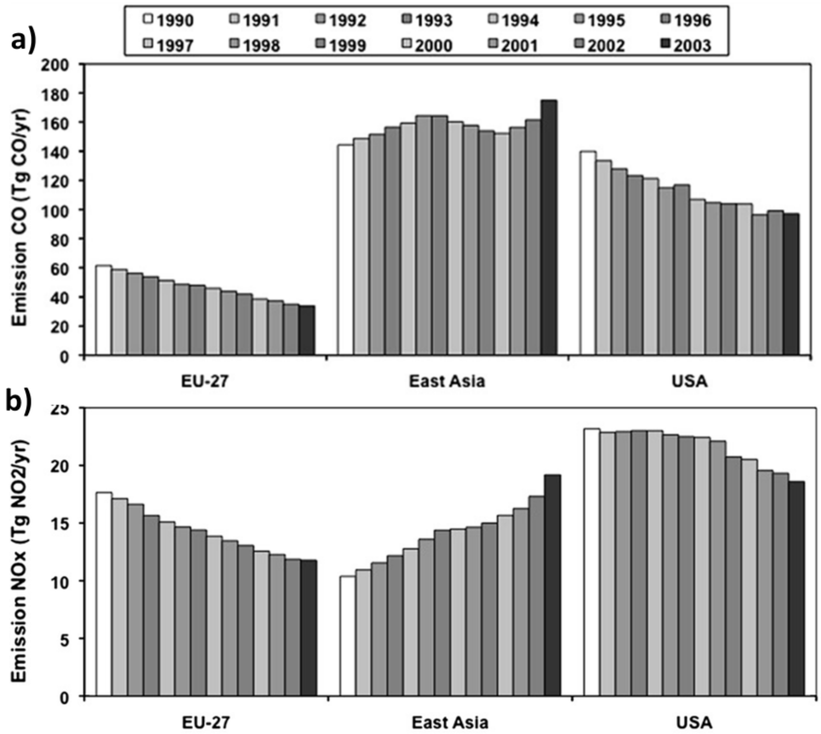

Figure3. CO (a) and NOx (b) emission evolution in Europe, East Asia, and U.S.A. for the period 1990-2003. (Monks et al., 2009).

From Figure 3 it can be realized that while trends in the developed world emissions show a decrease according to official reports from the Convention on Long-range Air Pollution (Europe) and National Air Quality and Emissions Trends Reports (U.S.A.), trends in developing countries emissions show an increase in the past few years and will continue increasing if the lack of control measures and atmospheric policies continues (Monks et al., 2009). Traffic road is strongly contributing to these trends and currently, traffic road emissions are of great importance especially in highly urbanized cities where the amount of motor vehicles is increasing. For instance, according to Tuia et al. (2007) vehicles generate 75% of the total emissions of CO and 60% of the total emissions of VOC in Chile.

In fact, motor vehicles contribute to the degradation of air quality by releasing pollutants such as CO, VOC, NOx, PM, and SOx. Once these pollutants are released to the atmosphere they are transported and dispersed, and in some cases they interact among other chemical species, light or heat bringing as consequence a chemical transformation or deposition (Martins et al., 2005).

Traffic road emissions depend on different characteristics of the vehicle fleet such as fuel used, engine type, model, and air conditioning system, among others. The main fuels used in transport sector are gasoline, diesel, natural gas, liquefied petroleum gas, ethanol, and methanol, depending on the type of vehicle, namely passenger car, buses, trucks, or motorcycles. The engine type also influences the amount and type of pollutants emitted, for instance, spark-ignition engines from gasoline-fueled vehicles can emit CO, NOx, hydrocarbons, and in some cases lead if it is leaded gasoline fuel. Diesel-fueled vehicles also emit particulate matter (PM) in addition to the previous mentioned pollutants emitted from gasoline-fueled vehicles (Onursal et al., 1997). According to traffic emission inventories developed in Italy by Bellasio et al. (2007), 53% of traffic emissions were CO emissions, followed by a 36% of PM, a 33% of VOC emissions, a 30% of NOx, and less than 1% of SOx.

Tuia et al. (2007) considers that in order to quantify the total emissions released from vehicles it is important to include three types of emissions:

- Hot emissions, which are released as a result of the normal activity of a vehicle and depend on the vehicle technology and driving conditions;
- Cold start emissions, which are released during the engine warming process;
- Evaporative emissions, which are released when the engine is turned off but is still warm, during normal vehicle activity, or during fuel recharge, they are linked to VOC emission.

Figure 4 illustrates the different ways in which emissions are released from vehicles. Evaporative emissions depend on the vehicle characteristics, as well as geographic and meteorological conditions, and they can occur as diurnal emissions which increase as temperature rises through the day, as running losses emissions, as hot soak emissions when the car is turned off, and as refueling emissions. Exhaust emissions are released as the result of fuel combustion, they depend on the vehicle fleet characteristics mainly vehicle technology, emission control systems, inspection and maintenance, driving conditions, and fuel characteristics (SEMARNAT, 2007).

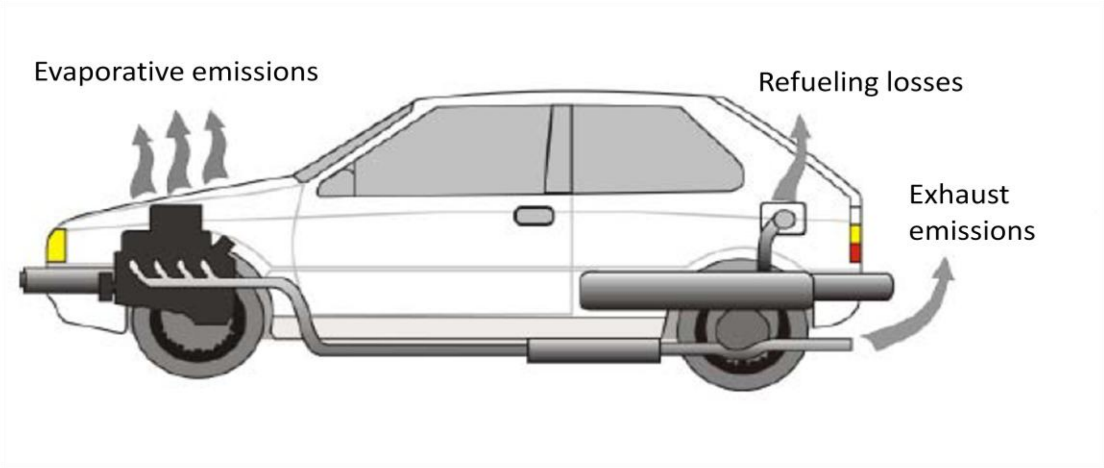

Figure 4. Emissions released by vehicles.

Parameters that give the magnitude, spatial, and temporal distribution of traffic road emissions are traffic activity which is related to traffic volume and vehicle-kilometers, and traffic performance related to travel speed, acceleration, and number of stops (Smit, 2006).

The importance of quantifying motor vehicle emissions is mainly due to population's exposure to the emitted pollutants and their impact on human health. According to the Health Effects of Transport-related Air Pollution Report released by the World Health Organization (WHO, 2005), the main aspects to be considered when assessing the level of population exposure to these emissions are volume and composition of traffic, distance between main roads and residence areas and workplaces, dispersion and weather conditions, and time spent in direct contact to the source. Health research indicates that the constant exposure to motor vehicle emissions can affect population health, causing allergic illness, respiratory diseases, cancer or even death.

3. Traffic emission inventories

Emission inventories allow the identification and quantification of atmospheric pollutant emissions in a defined area, and they are useful to assess global, regional, and even local scale environmental problems (Diem and Comrie, 2001). They also are a very useful tool during the decision making process when evaluating air quality improvement measures (Monteiro et al., 2007). Emission inventories should include information related to the atmospheric pollutants, the sources or activities that release these pollutants, emission factors, location and temporal variation of the emissions, among other characteristics needed to quantify atmospheric emissions

(Bellasio et al., 2007). An important aspect that must be considered when developing an atmospheric emission inventory is that it must have good practice guidance and moreover it must be accurate, comparable, and consistent (EMEP/EEA, 2009).

There are different methods that can be used for developing an atmospheric emission inventory and are applied according to the source of emission. Winiwarter and Schimake (2005) and Diem and Comrie (2001) defend two main approaches for emission inventories development:

- Bottom-up approach, which uses very specific and detailed information of the emission sources, and if possible continuous measurements and monitoring of emissions; even though some of the needed information is difficult to obtain this method is considered to provide high quality results and better representation of emission estimates
- Top-down approach, which mainly uses statistical data as indicators assuming that emissions are correlated with the indicator variables; the main goal is to disaggregate the data applying these indicators, is easier to develop and less expensive due to the resources needed

Motor vehicle emissions are one of the main concerns when dealing with air quality degradation in urban areas. For many cities in developed and developing countries the transport sector contributes in a high percentage to the overall anthropogenic emissions, in dense urban centers more than 50% of the overall emissions are traffic road emissions (Smit, 2006). Traffic emission inventories can help to identify which type of vehicles emit more pollutants to the atmosphere, to assess which modifications in fuel or vehicle technology can be made in order to decrease emissions, to show the spatial representation of these emissions helping in the identification of other sites which might experience a similar problem, and finally the results from the inventory can be employed as input data for pollution dispersion models (Bellasio et al., 2007; Baldasano et al., 2003). The aim of this chapter is to give a description of the top-down and bottom-up approaches used to develop a traffic emission inventories.

3.1 Top-Down approach

The top-down approach is very useful when specific data such as continuous monitoring of emissions are not available. In this case statistical data, which can be more accessible, is used to estimate emissions (Winiwarter and Schimake, 2005). This concept involves the disaggregation of, for instance, a national emission inventory to determine small scale regional emissions (Liobl et al., 1993). This means that first emissions are calculated for a big area and then using statistical information such as population census, economically active population, fuel consumption, vehicle type, etc., considered as indicators, the calculated emissions can be disaggregated to regional or municipal resolutions (Saija and Romano, 2002; Winiwarter and Schimake, 2005). Table 1 shows a list of the most commonly used indicators and the required data for the disaggregation of traffic emissions.

Table 1. Indicators used in top-down approach for traffic emission inventories (Saija and Romano, 2002; Tuia et al., 2002).

Indicators	Data
Fuel consumption	Fuel sales data
	Economically active population
Transportation use	Number of vehicle fleet
	Classification of vehicle fleet
Road network	Road density
	Road length/surface

Many cities especially in the developing world, which are considered mid sized cities, are starting to have problems with traffic emissions due to their urban growth, vehicle fleet increase, and lack of planning. For these cities it is difficult to implement a traffic model that requires very specific data because they lack of it and it is expensive, time consuming, and require specialized expertise (Tuia et al., 2007). Hence, the top-down approach is a good alternative to estimate traffic emissions in these smaller urban areas.

According to the simplified EMEP/CORINAIR methodology (EMEP/CORINAIR, 2007) used by the European Environment Agency (EEA), the emissions can be estimated using a total fuel consumption or mileage and then multiplied by an emission factor. The estimation can be done using the following expression,

$$E_{ij} = \sum_{j} (FC \times EF_{ij})$$

Where: E_{ij} is the amount of emission (g pollutant) of pollutant i released by vehicle of category j, FC is the disaggregation factor using indicator's data, and EF_{ij} is the specific emission factor (g/kg fuel, g/km) of pollutant i for vehicle category j.

This expression is considered to be easily applicable, but as it uses average values from different types of data, mainly provides a typical behavior of emissions more than an actual behavior (Borrego et al., 2000), and even though this approach is a useful method there are some problems associated to it, such as poor spatial distribution of emissions (Tuia et al., 2007). To deal with this problem some researchers have worked with different tools like Geographic Information Systems (GIS) to show the emissions in a higher spatial resolution.

GIS is a good tool that has improved the accuracy of traffic emission inventories by allowing data management (data storage, manipulation, and processing) by systematizing the way the inventory is developed and its final presentation (Dalvi et al., 2006). Figure 5 presents an example of the application of a GIS for a better representation of traffic emission inventories. The research developed by Dalvi et al. (2006) in India shows that by using GIS it can be easily distinguished in a more detailed scale the regions where emissions are higher or lower.

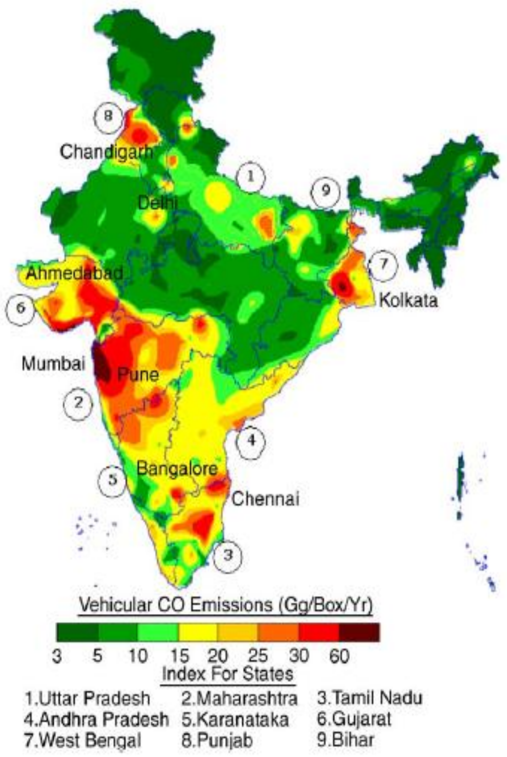

Figure 5. GIS application in top-down traffic emission inventories (Dalvi et al., 2006).

Moreover, GIS can be helpful for the interpretation of the results of traffic emission inventories due to its spatial distribution. In this work GIS will be used to provide a better representation of the results of the traffic emission inventory when applying the top-down approach.

Finally, even though this approach is widely used specially in developing countries, it is important to mention that there are limitations attached to it. First, the emissions calculated for a local area using surrogate data might be considered only as approximations of vehicle emission conditions (Wang et al., 2009). Second, the results from emission inventories are used as input data for dispersion models, and if this data differs a lot from reality then dispersion models will obtain erroneous results (Pratt et al., 2004). Also, as mentioned before, it is important to be conscious of the spatial accuracy of this approach (Osses de Eicker et al., 2008). For all these, other approaches such as the bottom-up approach can be used when data is available in order to have a more accurate emission inventory.

3.2 Bottom-Up approach

A more accurate identification and quantification of vehicle emissions can be achieved using the bottom-up approach, which can be based on the application of a traffic model to know the traffic flow in a specific area, and then of an emission model to calculate the total emissions in each road of the studied area (Tuia et al., 2007). Traffic models provide values regarding the spatial distribution of vehicle activity along the modeled area, and then this information together with emission factors, taken from the emission model, result in the estimation and distribution of vehicle emissions (Wang et al., 2009).

3.2.1 Modeling approach

There are different ways to develop a traffic emission inventory following a bottom-up approach, for this reason it is important to understand the general methodology employed. According to the EMEP/CORINAIR methodology (EMEP/CORINAIR, 2007) the bottom-up approach is considered to be a more detailed methodology to estimate vehicle emissions, it considers technical data such as emission factors and specific vehicle activity data. Figure 6 shows the different input variables and intermediate calculations applied by this methodology.

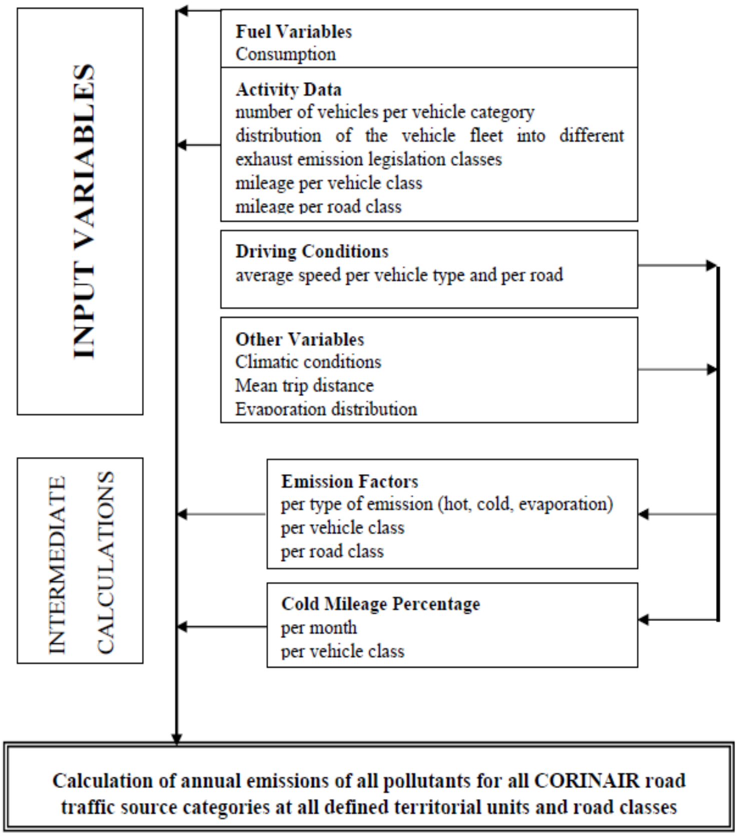

Figure 6. Input data and calculations applied in bottom-up methodology (EMEP/CORINAIR, 2007).

As it can be seen this methodology requires more detailed information, which in some cases is difficult to obtain, but necessary in order to have more accurate results.

a) Emissions calculations

Total vehicle emissions are obtained taking into consideration mainly two types of emissions: (i) hot emissions, which are released when the engine is in operation; and (ii) cold emissions, which are released during the warming-up phase or cold start of the vehicle. Also evaporative emissions caused from fuel evaporation can be considered. Total emissions can be calculated using the following equation:

$$E_{Total} = E_{Hot} + E_{Cold}$$

Where: E_{Total} is the total emissions (g pollutant) for the spatial and temporal resolution of the used model, E_{Hot} is the emissions (g pollutant) released during engine operation, and E_{Cold} is the emissions (g pollutant) released during warming-up phase of the vehicle.

As mentioned before hot emissions occur while the engine is thermally stabilized and they depend on different factors related to the vehicle's activity such as traveling distance, speed, road type, engine characteristics (age, size, weight). Hot emissions can be calculated with the following equation:

$$E_{Hot\ i,j,k} = N_j \times M_{j,k} \times e_{Hot\ i,j,k}$$

Where: $E_{Hot\ i,j,k}$ is the emissions of pollutant i (g pollutant) by vehicle class j driven on roads type k, N_j is the number of vehicles (veh.) of class j, $M_{j,k}$ is the mileage per vehicle (km/veh.) of vehicles class j driven on roads type k, and $e_{Hot\ i,j,k}$ is the emission factor (g/km) for the pollutant i, for vehicles type j, driven on roads type k.

On the other hand cold start emissions are considered as additional emissions and are mostly calculated for urban driving conditions as it is in urban areas where vehicles start and stop more frequently than in other driving conditions. The equation used to calculate cold start emissions is as follows:

$$E_{Cold\ i,j} = \beta_{i,j} \times N_j \times M_j \times e_{Hot\ i,j} \times \left(\frac{e^{Cold}}{e^{Hot}|_{ij}} - 1\right)$$

Where: $E_{Cold\ i,j}$ is the cold start emission of pollutant i (g pollutant) released from vehicle class j, $\beta_{i,j}$ is the fraction of mileage driven with cold engines for pollutant i and vehicle class j, N_j is the number of vehicles (veh) of class j, M_j is the total mileage per vehicle (km/veh) of class j, and $e^{Cold}/e^{Hot}|_{i,j}$ is the cold over hot emission ratio for pollutant i and vehicle class j.

Some of these parameters like $\beta_{i,\ j}$ and $e^{Cold}/e^{Hot}|_{i,j}$ depend on factors such as ambient temperature and vehicle use as well as driving behavior, furthermore they vary from country to country.

b) Vehicle emission factors

Vehicle emission factors can be described as the ratio between the amounts of pollutant emitted and the engine power or the fuel consumption or the distance travelled, and they are selected according to the available data or methodology. Emission factors related to engine power are expressed in kg of pollutant per kWh and annual engine operating hours are needed (EA, 2002). Fuel consumption emission factors are expressed in kg of pollutant per kg or m^3 of fuel and they depend on the type of fuel consumed for each specific vehicle category (EMEP/CORINAIR, 2007).

Emission factors related to distance travelled are expressed in g/km, they are dependent on different characteristics that need to be considered for their calculation such as vehicle and fuel types, vehicle usage (age, accumulated mileage, operation and maintenance), vehicle activity (speed, fraction of cold/hot starts, air conditioning use), and ambient parameters (Wang et al., 2009).

Even though sometimes is difficult to have access to this information, nowadays there are different techniques (direct and indirect) that can be used to estimate vehicle emission factors. The direct way to obtain emission factors is to have measurements directly from the source such as on board monitoring where emissions are monitored under real vehicle operation conditions. This type of measurements is usually expensive and need expertise and equipment to be performed, but if an appropriate selection of vehicles is done with a representative number of vehicles then significant results can be obtained to calculate accurate vehicle emission factors of a certain fleet. The indirect way is based on the use of data from measurements done in similar conditions, which are adjusted to the specific fleet and local parameters. There are some models that use data bases of measurements taken in different locations and combine them with local fleet characteristics, fleet activity, fuel, etc., to determine emission factors for each pollutant (SEMARNAT, 2007)

3.2.2 Models used to estimate vehicle emissions

Several computational models have been created in order to facilitate the development of traffic emission inventories. These models use as input data information related to fleet characteristics, vehicle activity, and local parameters to calculate vehicle emissions. Some of the most used models in developed and developing countries will be discussed as follows.

a) MOBILE Model

MOBILE model (EPA, 2003) is a mobile source emission factor model designed by the U.S. Environmental Protection Agency. This software is used to estimate current and future emissions from motor vehicles taking into consideration important aspects such as:

- Pollutants (hydrocarbons, carbon monoxide, nitrogen oxides, and others)
- Type of fuel (gasoline, diesel, natural gas)
- Type of vehicle fleet (passenger cars, buses, trucks, motorcycles)
- Time (calendar years between 1952 and 2050)

MOBILE has been applied in a state and local level for the development of vehicle emission inventories in the U.S.A., but it has also been applied in different countries around the world, especially where vehicle fleet is mainly characterized by U.S.A. technology, such is the case of Mexico where MOBILE was adapted to the Mexican vehicle fleet and conditions in order to estimate emission factors for this country (SEMARNAT, 2007). Emission factors are calculated in grams of pollutant emitted per vehicle mile traveled (g/mi) and then combined with travel activity estimates to get vehicle emissions expressed in tons per unit of time (hour, day, year) (EPA, 2003).

For the calculation of emission factors MOBILE takes into consideration 28 different vehicular categories which were selected according to vehicle usage, type of fuel, vehicle weight, and type of engine technology (EPA, 2003). These emission factors are calculated for different pollutants. Tables 2 and 3 show a list of MOBILE vehicle classification and the main pollutants categories employed.

Table 2. MOBILE vehicle classification (EPA, 2003).

Type of vehicle	**Description**
LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, greater than 5,751 lbs. ALVW)
HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
LDDV	Light-Duty Diesel Vehicles (Passenger Cars)

LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
MC	Motorcycles (Gasoline)
HDGB	Gasoline Buses (School, Transit and Urban)
HDDBT	Diesel Transit and Urban Buses
HDDBS	Diesel School Buses
LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

Table 3. MOBILE pollutant categories (EPA, 2003).

Pollutant	Description
HC	Hydrocarbons (gaseous)
CO	Carbon Monoxide (gaseous)
NOx	Oxides of Nitrogen (gaseous)
CO_2	Carbon Dioxide (gaseous)
SO_4	Sulfate Portion of Exhaust Particulate
OCARBON	Organic Carbon Portion of Diesel Exhaust Particulate
ECARBON	Elemental Carbon Portion of Diesel Exhaust Particulate
GASPM	Total Carbon Portion of Gasoline Exhaust Particulate
Lead	Lead Portion of Exhaust Particulate
SO_2	Sulfur Dioxide (gaseous)
NH_3	Ammonia (gaseous)
Brake	Brake Wear Particulate
Tire	Tire Wear Particulate
BENZ	Benzene
MTBE	Methyl Tertiary Butyl Ether
BUTA	1,3-Butadiene
FORM	Formaldehyde

ACET	Acetaldehyde
ACRO	Acrolein

Additionally, in order to estimate the emission factor for each pollutant and vehicle type MOBILE requires certain input data that have direct influence in the emissions and must be taken into consideration to obtain accurate results. Table 4 lists the input parameters required by MOBILE.

Table 4. MOBILE input parameters (EPA, 2003).

Input parameters	
Calendar year	Average trip length distribution
Month	Hot soak duration
Hourly temperature	Distribution of vehicle miles traveled by vehicle class
Altitude	Full, partial, and multiple diurnal distribution by hour
Weekend/Weekday	Inspection and maintenance (I/M) program
Fuel characteristics	Anti-tampering inspection program description
Humidity and solar load	Stage II refueling emissions inspection program
Registration (age) distribution by vehicle class	Natural gas vehicle fractions
Annual mileage accumulation by vehicle class	HC species output
Diesel sales fractions by vehicle class and model year	Particle size cutoff
Average speed distribution by hour and roadway	Emission factors for PM and HAPs
Distribution of vehicle miles traveled by roadway type	Output format specifications and selections
Engine starts per day by vehicle class and distribution by hour	Trip end distribution by hour
Engine start soak time distribution by hour	

MOBILE has default values for some of these parameters, but still it is important and necessary to use local data in order to reflect the real conditions of the studied area.

b) COPERT Model

The COmputer Program to Calculate Emissions from Road Transport (COPERT) (ETC/AEM, 2007) is a program developed to calculate emissions from road transport sector in the European Union. This model was specially created for vehicles with European technology and that follow European legislation. COPERT allows the development of national annual inventories, but it can also be applied for regional emission inventories with a spatial resolution of 1x1 km^2 and hourly temporal resolution (ETC/AEM, 2007).

COPERT calculates emissions of pollutants such as CO, NOx, VOC, and PM, as well as CO_2, CH_4, N_2O, NH_3, SO_4, heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs), and Persistent Organic Pollutants (POPs). The software includes emission factors for different vehicle categories, which combined with activity data, provide the total vehicle emissions (Ntziachristos et al., 2008).

The emissions are calculated for different vehicles categories taking into consideration fuel type (gasoline, diesel, and LPG), vehicle weight, and engine technology. Table 5 shows the description of the vehicle categories used by COPERT.

Table 5. COPERT vehicle categories (SEMARNAT, 2007; Ntziachristos et al., 2008).

Category	Description	Fuel	Classes	Technologies
Passenger Cars	Passenger vehicles with a maximum of 8 seats	Gasoline, Diesel, LPG	8	48
Light Duty Vehicles	Vehicles with weight less than 3.5 ton	Gasoline, Diesel	2	10
Heavy Duty Vehicles	Vehicles with weight greater than 3.5 ton	Gasoline, Diesel	15	71
Buses and Coaches	Vehicles with more than 8 seats	Diesel, CNG	6	29
Mopeds	2 or 3 wheeled vehicles, engine-less than 50 cc, speed-less than 40 km/h	Gasoline	1	4
Motorcycles	2 or 3 wheeled vehicles, engine-greater than 50 cc, speed-higher than 40 km/h	Gasoline	4	16

The program also requires general input data that varies according to the region or studied area. These input parameters are:

- Maximum and minimum monthly temperature,
- Fuel characteristics (vapor pressure, sulfur and lead content, hydrogen-carbon ratio, etc.),
- Fuel consumption data,
- Inspection and maintenance (I/M) program,
- Vehicular fleet distribution by class,
- Mileage driven by type of vehicle and road,
- Average speed distribution by type of vehicle and road,
- Number of vehicle starts by vehicle type,

- Average length driven.

c) IVE Model

The International Vehicle Emission (IVE) Model was created to develop mobile emission inventories especially in developing countries (Davis et al., 2005); it estimates vehicle emissions for any area taking into consideration tree main aspects:

1) Vehicle emission rates (emission factors and correction factors),
2) Vehicle activity (local data and driving behavior),
3) Vehicle fleet distribution (engine technology, air conditioning, etc.),

IVE model was developed jointly by the University of California at Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT), the Global Sustainable Systems Research (GSSR), the International Sustainable, Systems Research Center (ISSRC), and funding was provided by the U.S.A. EPA. This model has 7 vehicular categories and incorporates around 700 vehicle technologies which were defined according to the type of vehicles, type of fuel, different combinations of air/fuel controls, engine technology, among others. This allows the model to estimate emissions from different vehicle technology combinations. Table 6 shows the criteria used to define these vehicle categories (Davis et al., 2005).

Table 6. Criteria to define IVE vehicle categories (SEMARNAT, 2007).

Type of fuel	Fuel feed system	Vehicle usage	Emission control technology	Vapor recovery system
Gasoline	Carburetor	Less than 79,000 km	2-way catalyst	No control
Diesel	Pre-chamber injection	Less than 79,000 km		Ventilation valve
Compressed Natural Gas (CNG)	Single or multipoint fuel injection	Between 80,000 and 161,000 km	3-way catalyst	Ventilation valve and fuel tank control
Liquefied Petroleum Gas (LPG)	Multipoint fuel injection		Low emission vehicles	
Ethanol		More than 161,000 km	EURO I,II, III, IV, V	Evaporative emission control

For each technology a base emission running factor and a base emission starting factor are assigned (default factors), and as other models IVE uses the base emission rates for each technology and multiplies them by correction factors to obtain the total emissions from each vehicle type (Davis et al., 2005).

IVE model can estimate vehicle emissions for 15 pollutants categorized as (ISSRC, 2008):

- Pollutants: CO, VOC, evaporative emissions of volatile compounds (VOC evap), NOx, SOx, PM
- Toxic Pollutants: Lead, 1,3-Butadiene, Acetaldehyde, Formaldehyde, Ammonia, and Benzene
- Global Warming Pollutants: CO_2, N_2O, and CH_4

The general input data required by IVE are similar to the ones required by other models, namely (SEMARNAT, 2007):

- Temperature,
- Relative humidity,
- Detailed vehicle activity description from each vehicle category,
- Fuel characteristics,
- Inspection and maintenance program,
- Air conditioning usage,
- Altitude,
- Vehicle fleet distribution,
- Number of starts per day and vehicle category,
- Emission factors for each vehicle technology under local operation conditions,
- Vehicle specific power distribution.

According to Davis et al. (2005) studies were conducted in different countries like India, Brazil, Nairobi, Mexico, among others, using IVE model to create vehicle emission inventories. Specifically for Mexico, field studies were conducted to gather information about the vehicle activity and vehicle fleet and determine local on-road emissions to improve future Mexican emission inventories (Davis et al., 2004).

d) MOVES Model

MOVES is a Motor Vehicle Emission Simulator (EPA, 2010) developed by the U.S.A. EPA to estimate mobile source emissions applying different user-defined conditions that can give additional information about specific scenarios. These user-defined conditions are specific data about vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types (EPA, 2010). The main difference with the EPA MOBILE model is that MOVES uses databases to obtain more specific results for a certain location. This model can be used to estimate emissions from air pollutants, greenhouse gas emissions, and some toxic pollutants in a national, state, and county level.

To define the different vehicle categories MOVES uses as main criteria the vehicle usage, activity patterns, and energy consumption getting 13 main categories, which are subcategorized into more detailed subcategories according to fuel type, engine technology, model year, and vehicle weight. Table 7 includes some of the elements considered for vehicle characterization (SEMARNAT, 2007; EPA, 2010).

Table 7. Elements considered by MOVES for vehicle characterization (SEMARNAT, 2007; EPA, 2010).

Fuel type	Engine technology	Vehicle weight (lb)	Engine size (L)
Gasoline	Internal combustion	<500	<2.0
Diesel	Conventional	500-700	2.6-3.0
Natural Gas	Internal combustion	>700	3.5-4.0
CNG	Advanced	<2000	4.1-4.5
LPG	Hybrid-internal combustion	3001-3500 3501-4000 4001-4500	
Ethanol	Advanced	4501-5000	
Methanol	Fuel cell	26001-33000 33001-40000	
Hydrogen Gas	Electric	50001-60000 60001-80000	
Liquid Hydrogen		80001-100000 100001-130000	
Electricity		>130001	

MOVES has default input data assigned especially for U.S.A vehicle fleet. In order to have an accurate emission inventory it is necessary to have at least the base year and month, temperature, relative humidity, fuel characteristics, vehicle fleet distribution, driven distance, average speed distribution, number of starts per vehicle, and inspection and maintenance program as input parameters (SEMARNAT, 2007).

e) TREM Model

TREM- Transport Emission Model for Line Sources (UA, 2007) is a model developed at the University of Aveiro to quantify road traffic emissions based on the MEET/COST (Methodologies to Estimate Emissions from Transport/Estimation of Emissions from Transport). This model can be used at urban level and with hourly emission estimations, additionally it works in GIS environment.

TREM calculates hot emission, cold start emissions, and evaporative emissions from different vehicle categories such as gasoline, diesel and LPG passenger cars, gasoline and diesel light duty vehicles, diesel heavy duty vehicles, urban busses, coaches, and motorcycles. Vehicle classification is based on model year, engine type and capacity, and emission standards. TREM calculates emissions from pollutants such as CO, NOx, VOC, CO_2, SO_2, and PM. One of the differences with the other models previously mentioned is that TREM is linked to a transportation model to obtain traffic volume data and to an air quality model to calculate pollutant concentrations. In order to obtain emission estimates this model requires data related to each road segment analyzed such as traffic volume, vehicle speed, vehicle distribution by categories and classes, as well as road segment length. TREM has a simple and user friendly graphic interface, it allows the identification of possible errors attached to input data in order to get accurate results. The output data is given in [g/km] or in [g] for each road segment analyzed. (UA, 2007)

Figure 7 shows a brief summary of the main characteristics of the models previously described; as it can be seen all of them have some similarities especially the fact that they require specific data from the area where the emission inventory is being developed.

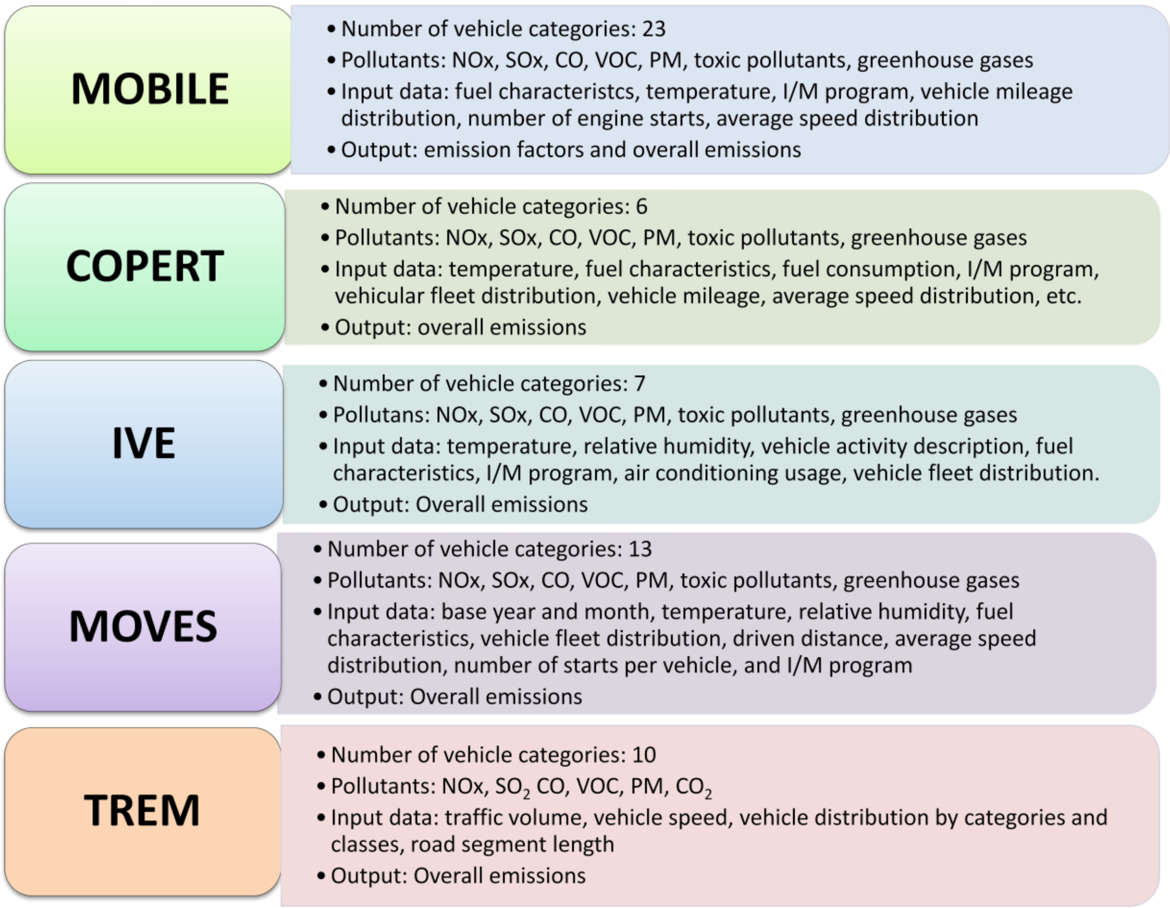

Figure 7. Characteristics of vehicle emission models.

The different approaches used to create emission inventories (top-down and bottom-up) differ from each other in many aspects, each of them has its benefits and limitations and their application depends on the need and on data availability of the study area. Top-down approach is a simple methodology commonly used to estimate regional or local emissions from the disaggregation of an existing inventory using surrogate data. While top-down approach is useful to develop inventories where specific vehicle activity data is not available, bottom-up approach applies a more detailed methodology using traffic models and vehicle emission models to calculate in a more accurate way emissions released from mobile sources. These models also have different characteristics and can be used according to the needs of the inventory. Regardless which of the approaches is followed it is important to consider that in order to have an accurate emission inventory consistent and precise data is needed.

4. Development of a traffic road emission inventory for the city of Querétaro, Mexico

Nowadays air quality in Mexico is a priority for environmental authorities and for society in general due to health problems and atmospheric degradation associated to air pollution in the last decades. For these reasons some efforts have been carried out around the country in order to have a more efficient air quality management. Among these efforts a National Emission Inventory was created as well as some air pollution control programs, and new standards related to atmospheric emissions have been established. However, the lack of emission inventories in many Mexican cities brings as consequence a gap between what has being done and the real situation these cities are facing regarding atmospheric emissions. In this scope this study is focused in the development of a traffic emission inventory for a mid-sized city of Mexico, named Querétaro, to serve as a background or comparison for future studies developed in this area.

4.1 Case study description

One of the most important attempts developed in order to deal with air pollution in Mexico was the creation of the 1999 Mexico National Emission Inventory (NEI) which is the first state level emission inventory for the country. The objective of the inventory was to obtain emission estimates for the entire country at a state level focusing on NOx, SOx, VOC, CO, PM, and NH_3 emissions and for point, area, natural, motor vehicles, and non-road mobile sources for the base year 1999 as this was the year were most of the state environmental agencies have complete data needed for the inventory (SEMARNAT, 2006).

According to the 1999 Mexico NEI, motor vehicle source has a significant importance in the overall emissions in the country. As shown in figure 8 motor vehicles contribute to around 60% of CO emissions, following by 49% of NOx, 23% of VOC, 7% of PM_{10}, and 1% of SOx. For the purpose of this work only the results from motor vehicle sources will be taken into consideration.

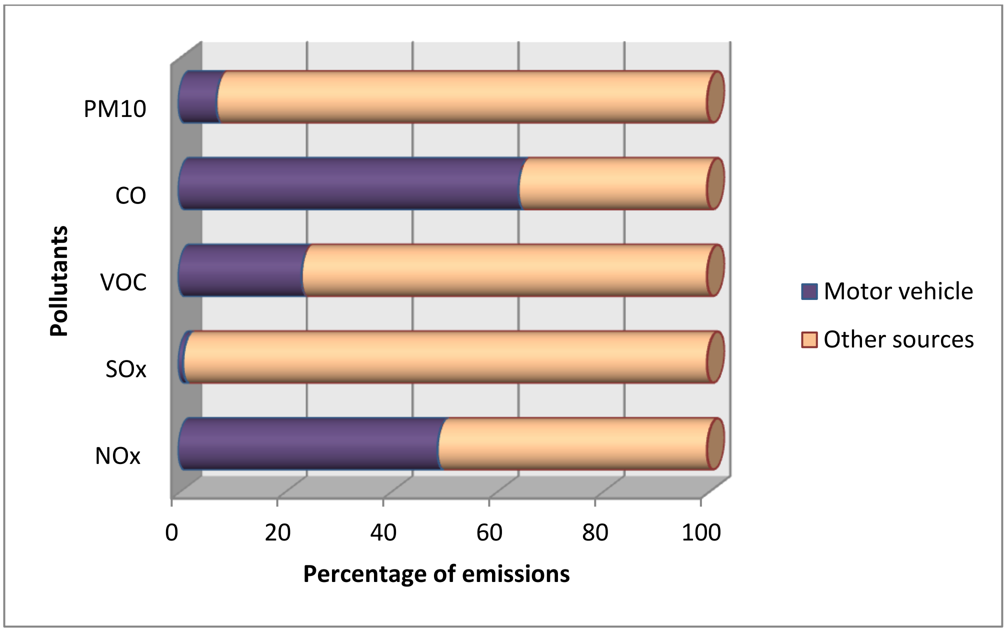

Figure 8. Contribution of motor vehicle emissions in México (SEMARNAT, 2006).

The states with larger population such as Estado de México, Distrito Federal, Jalisco, and Nuevo León were identified as the ones which emitted the higher amount of pollutants. This agrees with the report released by the Mexican Association of Vehicle Distribution (AMDA, 2005), that states that 45% of Mexican fleet is distributed mainly in five states: Distrito Federal (17%), Jalisco (9%), Estado de México (7%), Nuevo León (6%), and Baja California (6%). One of the most important aspects considered in this inventory concerns vehicle fleet characterization, which; unfortunately is difficult to characterize in Mexico. The Mexican vehicular fleet report (AMDA, 2005), mentions an average age of vehicles in Mexico as approximately 14 years, with a high number of old vehicles and without maintenance. According to Cruz et al. (2008) one factor that affects vehicle characterization is the illegal imported vehicles coming from the U.S.A.

As motor vehicle emissions have become of great importance for Mexican environmental authorities, the General Law of Ecological Balance and Environment Protection (Ley General de Equilibrio Ecológico y Protección al Ambiente LGEEPA) stipulates that the environmental agency in Mexico (SEMARNAT) must develop and update an atmospheric emission inventory for sources under federal jurisdiction. Furthermore, several standards were created regarding motor vehicle emissions in order to decrease them. Some of the standards are:

- NOM-041-SEMARNAT-2006 – establishes the maximum limits allowed of pollutants emitted from motor vehicle exhaust , this is applicable for vehicles powered by gasoline;

- NOM-042-SEMARNAT-2003 – establishes the maximum limits allowed of VOC, CO, NOx, and PM emitted from motor vehicle exhaust, this is applicable for vehicles (not greater than 3857 kg) powered by gasoline, diesel, LPG, and natural gas;
- NOM-044-SEMARNAT-2006 – establishes the maximum limits allowed of VOC, CO, NOx, and PM emitted from motor vehicle exhaust, this is applicable for new vehicles (greater than 3857 kg) powered by diesel.

Apart from the México 1999 NEI other local inventories have been created within the program to improve air quality in México – the PROAIRE (Programs for the improvement of Air Quality), developed by SEMARNAT and the National Institute of Ecology (INE). The local developed inventories concern the following cities:

- Guadalajara (1995) - is the second most populated area; motor vehicles emit 90% of the overall NOx, CO, and VOC emissions;
- Monterrey (1995) - is the third largest city in México; motor vehicle emissions are 60% of the total NOx, CO, and VOC;
- Ciudad Juárez (1996) - is the largest city located across the U.S.A.- Mexican border south of Texas; motor vehicles have an important contribution to the total emissions;
- Tijuana (1998) - also located across the U.S.A. - Mexican border south of California; motor vehicles emit the majority of the total NOx, VOC, and CO;
- Mexico City Metropolitan Area (2000) - is the most populated area in the country; motor vehicle emissions were identified as the main contributors to the overall emissions.

Unfortunately several urban areas are not covered yet by emission inventories. Mid-sized cities can also have traffic road emissions strongly contributing to the air quality degradation. Therefore there is a need of developing more inventories in other cities in Mexico, like Querétaro, as well as updating the existing ones.

The state of Querétaro is located in the central region of México at 21°40' north, 20°01' south (latitude) and 99° 03' east, 100° 36' west (longitude), covering an area of 11,769 km^2 it represents 0.6 per cent of the total Mexican surface. It is bordered on the north by the state of San Luis Potosí, on the south by the states of México and Michoacán, on the east by the state of Hidalgo, and on the west by the state of Guanajuato. The state of Querétaro has eighteen municipalities and its capital city is Querétaro city (INEGI, 2000). Figure 9 shows the location of the state of Querétaro.

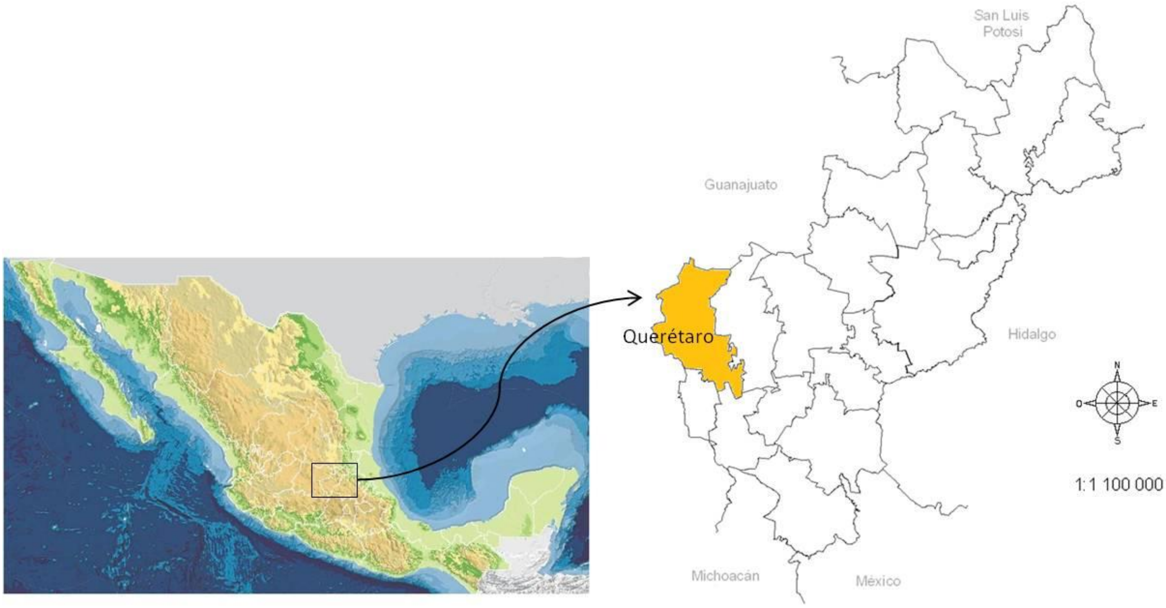

Figure 9. Location of the state and the municipality of Querétaro, México (INEGI, 2000).

Results from the 1999 NEI show that the state of Querétaro contributes to the total national emissions as: 1% NOx, 1.1% SOx, 1% VOC, 1.1% CO, and 1.1% PM. The annual vehicle emissions for the state of Querétaro are shown in Table 8.

Table 8. Annual vehicle emissions for the state of Querétaro (SEMARNAT, 2006).

State	**Annual Emissions (Mg/year)**				
	NOx	SOx	VOC	CO	PM
Querétaro	4,762.9	278.1	6,124.1	52,195.1	233.9

Even though this contribution does not seem significant the city of Querétaro, according to the last population census in 2010 had 801,940 inhabitants (INEGI, 2011), has experienced a continuous and important socio-economic growing since the year 2000. The city of Querétaro is located at 20° 35’ north latitude and 100° 23’ west longitude, at 221 km northeast of Mexico City.

In fact, Querétaro’s population rate has increased 4.59% from the last 10 years (INEGI 2011). This has also been reflected in an increment of the vehicle fleet, which according to INEGI has increased 7.9% since the year 2000 (INEGI, 2011). For this reason the development of traffic road emission inventories may be seen as a summing effort to identify the amount of contaminants emitted in this urban area, and as a start to elaborate vehicle emission inventories to form a database that can be use to reflect the current situation and future projections of vehicle emissions in order to create control programs that improve air quality management in Querétaro.

Therefore the geographic domain of the inventory covers the city of Querétaro, which fits with the municipality of Querétaro, and thus the spatial resolution goes till the municipality level. The base year of the vehicle emissions estimation is 2005, because most of the available and more recent data concern this year. Annual emissions were estimated, as well as daily emissions.

The main pollutants usually associated to traffic road emissions were considered, namely: nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), and particulate matter (PM).

One of the most important stages in the development of this inventory was the collection of relevant data from public and private entities. As it was not possible to have field work to develop a vehicle technology distribution to know the exact vehicle activity and classification in Querétaro, data was reviewed and used from previous studies developed in Querétaro or in similar Mexican cities and adapted to the current situation of the study area. Table 9 shows the required data and the different sources reviewed for the two methodologies.

Table 9. Required data and sources reviewed.

Activity	Required data	Source
Characterization of main roads	Identification of main roads in Queretaro (location, length)	http://www.concyteq.edu.mx/cqrn3/descargas.php http://inegi.gob.mx http://earth.google.es/ (Google Earth 6)
	Characterization of highways, arterial, second arterial, and local roads (average speeds)	Traffic law and traffic regulation of the state of Queretaro (MEXICO. Ley de Tránsito del Estado de Querétaro, 2001; MEXICO. Reglamento de Tránsito del Estado de Querétaro, 2001)
Characterization of vehicle activity	Vehicle driving patterns and vehicle start patterns	Mexico city vehicle activity study (Davis et al., 2004)
	Driven kilometers per vehicle and by road classification	Measurement and adaptation of vehicle activity variables in Mexican sample cities (CCA, 2009) Measurement and analysis of traffic volume in main roads in Queretaro City (CONCYTEC, 2006)
	Vehicle traffic counts for main roads in Queretaro	Measurement and analysis of traffic volume in main roads in Queretaro City

		(CONCYTEC, 2006)
Characterization of vehicle fleet	Vehicle technology distribution	Mexico city vehicle activity study (Davis et al., 2004)
	Vehicle fleet classification by technology and fuel usage	Data from local authorities • Secretariat of Sustainable Development in Querétaro SEDESU Statistical annual yearbook for transportation sector in the state of Querétaro (INEGI, 2005)
Fuel characterization	Properties, characteristics, and specifications of Mexican fuel (sulfur content, density)	Gasoline, Diesel and LPG PEMEX safety data sheets Unit conversion guideline-National Energy Information System (OLADE, 2004)
	Fuel sales data for the state of Querétaro	Petróleos Mexicanos (PEMEX) internal fuel sales data for Querétaro - year 2005 (PEMEX, 2011)

The table presented above shows the minimum required data used for the development of the top-down and bottom-up vehicle emission inventories, covering data from characterization of roads, vehicle fleet, vehicle activity and fuel consumption. This data was gathered from official studies, methodological guidelines, national and state inventories, governmental reports, and Mexican regulations.

4.2 Methodology

For the development of this motor vehicle emissions inventory two different methodologies were followed, top-down and bottom-up. The purpose was to obtain the most complete picture of Querétaro traffic road emissions based on both approaches results and, if possible, merging them.

Figure 10 illustrates the methodologies applied for the development of the traffic emission inventory for Querétaro.

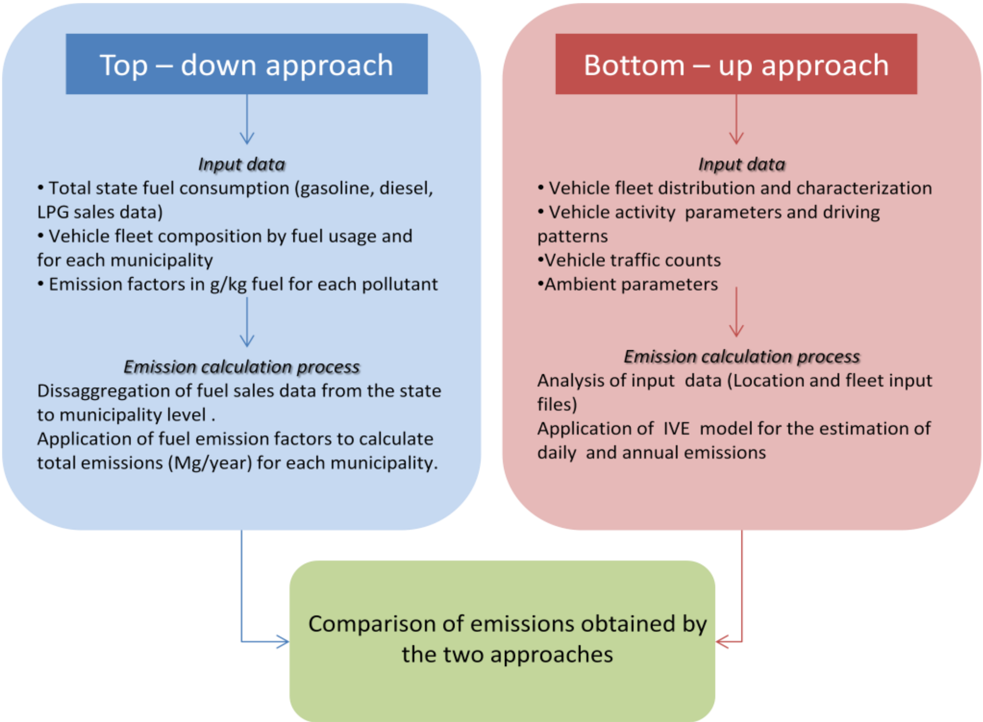

Figure 10. Proposed methodologies for the development of a traffic emission inventory.

It can be observed the differences between both methodologies; however it is important to make a comparison of the obtained emission values to demonstrate the agreement between both methodologies. The combination of these two methodologies may be useful for the development of a complete emission data used for air quality modeling.

4.2.1 Top- down methodology

A top-down methodology was applied for the estimation of motor vehicle emissions for Querétaro. A modification to the typical top-down approach was needed, instead of disaggregating the total state vehicle emissions as commonly made, fuel sales data were disaggregated from the state to the municipality level, and then by applying fuel emission factors (g/kg fuel) emissions released by each fuel were calculated. The total emission was considered as the sum of all fuel emissions. The fuels considered were gasoline, diesel, and LPG. This modification was needed because it was necessary to consider the contribution of the emissions from the different fuels used in Querétaro.

The total emission estimates were based on equation 5:

$$E_i = Eg_i + Ed_i + Elpg_i$$

Where: E_i is the total emission of pollutant i (Mg/year), Eg_i is the emission of pollutant i released by gasoline powered vehicles (Mg/year), Ed_i is the emission of pollutant i released by diesel powered vehicles (Mg/year), and $Elpg_i$ is the emission of pollutant i released by LPG powered vehicles (Mg/year).

Emissions released by each fuel were estimated using the following equation:

$$E_{ij} = FS_j \times CF_j \times EF_{ij}$$

Where: E_{ij} is the emission of pollutant i released by vehicles using fuel j (Mg/year), FS_j is the fuel j sales for each municipality (m^3/year), CF_j is the conversion factor (based on density of each fuel), and EF_{ij} is the Fuel j emission factor for pollutant i (g/kg fuel).

To obtain fuel sales for each municipality, in particular Querétaro municipality, and because this information was not available, the disaggregation was based on fuel consumption using fuel sales data of the state of Querétaro for the year 2005 (provided by the Mexican oil company PEMEX) and on total vehicle fleet counting classified by fuel usage and by municipality. Fuel sales for each municipality were calculated as follows:

$$FS_j = \frac{VF_j \times TFS_j}{TVF_j}$$

Where: FS_j is the fuel j sales for each municipality (m^3/year), VF_j is the number of vehicles using fuel *j* by municipality, TFS_j is the total fuel j sales for the state of Queretaro (m^3/year), and TVF_j is the total number of vehicles using fuel j in the state of Querétaro.

As fuel sales are given in m^3/year and the fuel emission factor in g/kg of fuel a conversion factor is needed in order to give the emission estimates in Mg/year. This conversion factor was obtained using fuel density (ton/m^3) and divided by 1000. Fuel density was obtained according to the fuel characteristics in México. Table 10 presents a summary of some of the collected data.

Table 10. Vehicle and fuel characteristics.

Fuel	Density (ton/m^3)	Vehicle fleet for the state of Querétaro	Fuel sales for the state of Querétaro (m^3/year)
Gasoline	0.75	263,650	910,651.7
Diesel	0.94	9,191	630,469.6
LPG	0.55	287	229,649.1

Fuel sales data and fuel emission factors were used as surrogate data to estimate emissions from motor vehicles, and for this different fuel emission factors were reviewed. Emission factors expressed in grams of pollutant emitted per kilogram of fuel instead of grams of pollutant per kilometer traveled were selected because fuel sales data were estimated according to the vehicle fleet and fuel usage instead of kilometers traveled, and assuming that all the fuel is consumed in each municipality where it is sold emitting all the pollutants in this area. The fuel emission factors for NOx, VOC, and CO were selected from the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996), which considers emission factors covering U.S.A and European vehicles. For the purpose of this thesis emission factors were selected assuming that vehicle technology in México is similar to U.S.A. vehicle technology so emission factors from U.S.A. vehicle fleet were considered. Emission factors for PM were selected from the Australian Emission Estimation Technique Manual (EA, 2002). Table 11 shows the selected emission factors.

Table 11. Selected fuel emission factors.

Fuel	**Emission factors (g/kg fuel)**			
	NOx	VOC	CO	PM*
Gasoline	9.44	38.86	240.86	7.26×10^{-4}
Diesel	27.37	4.12	14.87	3.61×10^{-3}
LPG	16.8	23.5	70.6	NA

(*) Emission factors in kg/L; NA: Not Available

To evaluate the emission estimates, the total emissions for the state of Querétaro were also calculated using the same approach and compared to the emission estimates from the Mexico 1999 NEI for the state of Querétaro.

Finally, for a better visualization of the results, different maps were created using the software ArcGIS 10 to show the emission estimates for each pollutant, municipality, and depending on fuel usage.

4.2.2 Bottom-up methodology

The bottom-up approach was used in this inventory to calculate emissions from the main roads in the city of Querétaro. For this methodology the IVE traffic model was employed. The selection of this model was done after reviewing and comparing some traffic models existing for the calculation of vehicle emissions and previously described. The criteria used for the selection is summarized on Table 12, and includes characteristics as the spatial and temporal resolution of the results and/or the availability of a model technical manual.

Table 12. Criteria used for the selection of the traffic model.

Model	Model Characteristics					
	Spatial and temporal resolution	Vehicle categories	Data requirements	User friendly	Free access	Available guide/manual
MOBILE 6	+	+	+	-	+	+
MOVES	+	+	+	-	+	+
COPERT 4	+	-	+	+	+	+
IVE	+	+	+	+	+	+
TREM	+	-	+	+	+*	+

(+) the model fulfills the requirement, (-) the model does not fulfill the requirement for the development of the emission inventory, (+*) free access available only for UA students.

After reviewing the characteristics of different vehicle emission models, the IVE model was the one fulfilling all the requirements for the development of this emission inventory. It can estimate emissions at a high spatial and temporal resolution, it also includes vehicle categories from the U.S.A. as well as European. Even though data requirements are similar to the other models and in some cases not available, the IVE model has default data applied for developing countries which can be modified if local data is available. The software is simple, user friendly, and it can be easily downloaded from the official IVE website without any cost, additionally a complete user guide is available as well as vehicle emission and vehicle activity studies applying IVE model in developing countries.

Figure 11 shows the scheme of the IVE model structure. The input data is given by two input files containing all the information required to run the model. The two input files are the location file which includes specific information about the location and the vehicle activity, and the fleet file including data about the vehicle fleet characterization. The calculation process is based on an emission rate and a series of correction factors. Finally the model outputs are the running and start emissions released during the day.

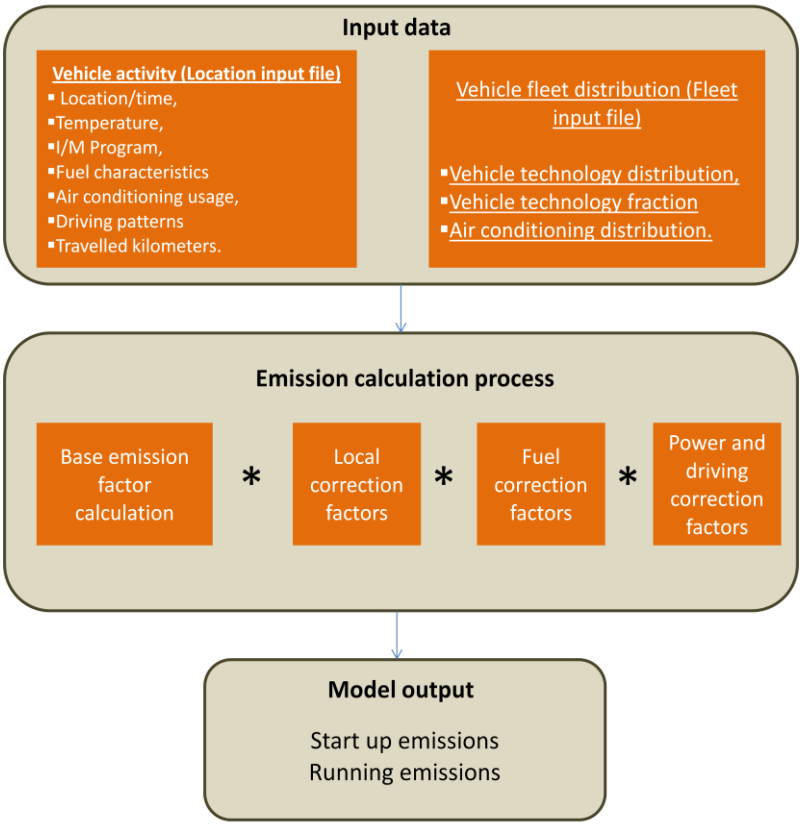

Figure 11. IVE model structure.

The emission calculation process of the IVE model is done by using the base emission rate for each vehicle technology and correction factors established for each vehicle technology too. The internal emission estimation process of the model is given by Equation 7.

$$E_t = B_t \times C_{1,t} \times C_{2,t} \times \ldots .. C_{n,t}$$

Where: E_t is the emission rate for each vehicle technology *t* (start (g) or running (g/time)), B_t is the base emission rate for each technology *t* (start (g) or running (g/time)), and $C_{1,t}$, $C_{2,t}$, $C_{n,t}$ are correction factors.

The IVE model identifies two types of base emission rates: running emissions (g/time), which are dependent on the travel fraction for each technology, velocity, and driving type and start emissions (g) which depend on the number of starts. The average running emissions in g/km can be obtained by dividing the running emission rate (E_t) by the velocity (km/h) from the specific driving segment analyzed.

The correction factors are divided into local variables (ambient temperature, ambient humidity, altitude, I/M programs), fuel quality variables (gasoline overall, gasoline sulfur, gasoline leaded, gasoline oxygenate, diesel overall, diesel sulfur), and power and driving variables (vehicle specific power, road slope, air conditioning usage, start distribution). The value of these correction factors depends on the entries selected in the input files required by the model. The used motor vehicle categories were based on the IVE's vehicle classification adjusted to the Mexican vehicle fleet. Some characteristics of Mexican vehicle classes according to weight and engine size are:

- Passenger vehicles-Light: Vehicles with a 1.5 L or smaller engine and weighs less than 5000 pounds,
- Passenger vehicles-Medium: Vehicles with 1.5-3 L engine and weighs less than 6600 pounds,
- Passenger vehicles-Large: Vehicles with more than 3 L engine and weighs between 6600 and 9000 pounds,
- Small trucks: Trucks between 9000 and 14000 pounds,
- Medium trucks: Trucks between 14000 and 33000 pounds with single rear axle,
- Large trucks: Trucks weighing more than 33000 pounds and with double rear axle,
- Small bus: Buses weighing less than 14000 pounds for 8 to 19 passengers,
- Medium bus: Buses between 14000 and 33000 pounds for 20 to 45 passengers,
- Large bus: Buses weighing more than 33000 pounds for more than 45 passengers.

Gasoline, diesel, and LPG powered vehicles were considered. The vehicle technology distribution was based upon engine technology, control technologies, and fuel used. Table 13 shows vehicle characterization for vehicle fleet and vehicle fraction for the city of Querétaro. The vehicle fraction is considered as the fraction of vehicles related to each vehicle technology, this fraction was obtained from a vehicle activity study developed specifically for Mexican fleet adapted for vehicle fleet in Querétaro (Davis et al., 2004). The vehicle characterization and vehicle fraction data are needed in order to create an input file with the vehicle fleet of Querétaro.

Table 13. General characteristics of vehicle fleet in the city of Querétaro.

Type of vehicle	Characteristics	Fraction
Passenger vehicle	Gasoline, 4-stroke, Carburetor, no catalyst control	0.26
	Gasoline, 4-stroke, Single point fuel injection, no catalyst control	0.02
	Gasoline, 4-stroke, Single point fuel injection, 3-way catalyst control	0.05
	Gasoline, 4-stroke, Multipoint fuel injection, no catalyst control	0.03

	Gasoline, 4-stroke, Multipoint fuel injection, 3-way catalyst	0.63
Buses	Gasoline, 4-stroke, Carburetor, No catalyst control	0.46
	Gasoline, 4-stroke, Carburetor, 3-way catalyst	0.24
	Gasoline, 4-stroke, Multipoint fuel injection, No catalyst	0.024
	Gasoline, 4-stroke, Multipoint fuel injection, 3-way catalyst	0.01
	LPG, Carburetor, No catalyst	0.26
	LPG, Carburetor, 3-way catalyst	0.01
Trucks	Diesel, Pre-Chamber injection, No catalyst	0.23
	Diesel, Direct Injection, Improved emission control	0.77

After creating the fleet file, the location input file is required by the IVE model with the driving behavior, start patterns, fuel characteristics, and the environmental conditions for the city of Querétaro.

Based on measurements of traffic volume in the main roads in Querétaro, which were performed by the Science and Technology Institute (CONCYTEC, 2006), eleven roads were considered as main roads, and classified into 4 types of roads: highway, arterial, second arterial, and local. The location file was created for these main roads in Querétaro, which are shown in Figure 12 and presented on Table 14.

Figure 12. Road network for the city of Querétaro (INEGI, 2000).

Table 14. Roads considered for traffic counting (CONCYTEC, 2006) and selected for emissions estimation.

No.	Road	Road type	Road length (km)
1	Highway México-Querétaro	Highway	4.55
2	Highway Querétaro-Celaya	Highway	7.19
3	Av. Bernardo Quintana	Arterial	9.3
4	Av. 5 de Febrero	Arterial	5.59
5	Av. Pie de la Cuesta	Arterial	4.82
6	Ignacio Zaragoza	Second Arterial	2.81
7	Luis Pasteur	Second Arterial	2.24
8	Universidad	Second Arterial	4.23
9	Revolución	Second Arterial	1.85
10	Corregidora	Local	1.1
11	Benito Juárez	Local	1.1

Traffic countings during different hours of the day were taken into consideration to create a temporal vehicle profile and to estimate the amount of driving kilometers and starting patterns. Figure 13 shows the averaged hourly values from all the roads from each type of road considered in the traffic counting. As it can be observed there are a higher number of vehicles traveling in highways, followed by arterial roads. Also an increment of vehicular activity can be observed during three peak hours in the morning, afternoon and evening.

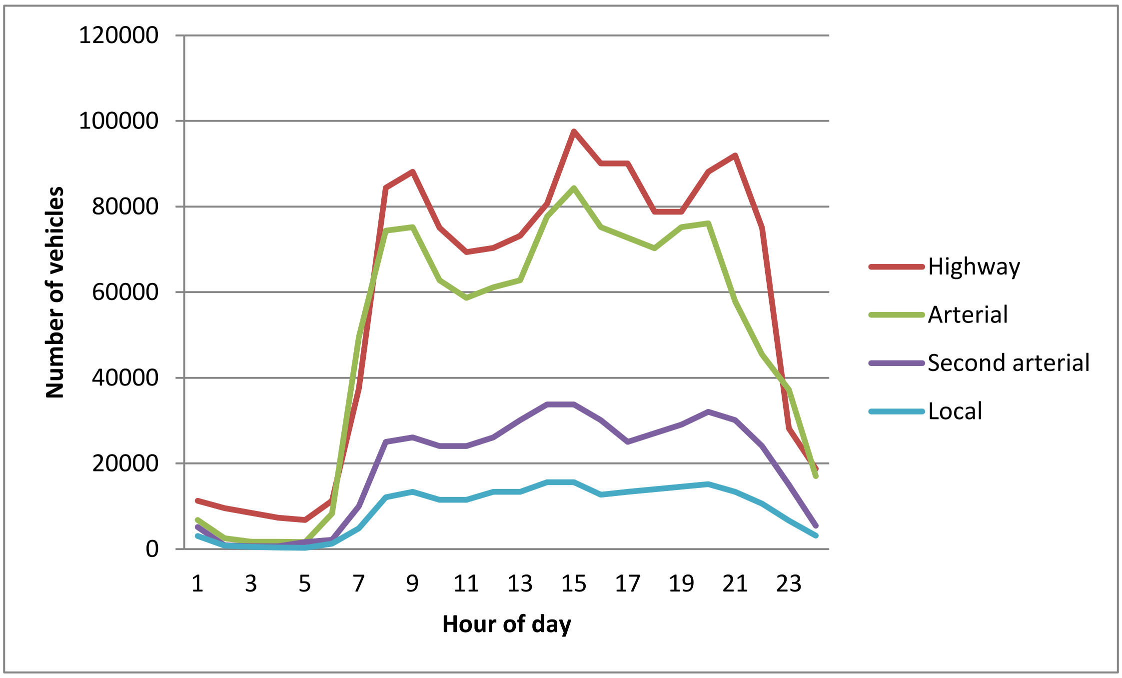

Figure 13. Temporal vehicle profile by road type in Querétaro (CONCYTEC, 2006).

Table 15 contains the average speeds considered for each type of road according to the traffic regulations for the state of Querétaro concerning passenger vehicles, buses and trucks travelling through each type of road. This table also shows the averaged number of vehicles circulating in each road type.

Table 15. Traffic counting and average speeds for the main roads in Queretaro (CONCYTEC, 2006).

Type of road	Average speed (km/hour)			Number of vehicles by road type			
	PC	Bus	Truck	Total	PC Vehicles	Buses	Trucks
Highway	80	60	60	112,531	100,040	5,063	7,314
Arterial	60	40	40	85,166	75,372	5,280	4,088
Second Arterial	40	30	30	34,092	28,501	4,186	1,295
Local	30	20	NA	15,763	15,652	110	0

NA= Not applicable

Vehicle activity including travelled kilometers were gathered from the following sources: Measurement and adaptation of vehicle activity variables in Mexican sample cities (CCA, 2009), Measurement and analysis of traffic volume in main roads in Queretaro City (CONCYTEC, 2006), and data from local authorities (Secretariat of Sustainable Development in Querétaro SEDESU, 2011). The temporal vehicle activity distribution for each road type is shown in table 16.

Table 16. Travelled kilometers by hour by road type.

Time of Day	Highway	Arterial roads	Second Arterial roads	Local roads
	Travelled kilometers	Travelled kilometers	Travelled kilometers	Travelled kilometers
0:00	66,056	36,555	15,765	3,329
1:00	56,147	13,708	2,628	867
2:00	49,542	9,139	2,102	520
3:00	42,936	9,139	2,102	347
4:00	39,633	8,682	4,940	329
5:00	66,056	44,323	6,727	1,335
6:00	220,164	265,935	30,900	5,323
7:00	495,418	398,903	77,250	13,333
8:00	517,414	403,472	80,298	14,668

9:00	440,327	336,760	74,097	12,657
10:00	407,299	314,827	74,097	12,657
11:00	412,848	328,078	80,298	14,668
12:00	429,362	336,760	92,700	14,668
13:00	473,355	416,723	105,102	17,338
14:00	572,439	456,933	105,102	17,338
15:00	528,446	403,472	92,700	13,992
15:00	528,446	390,221	77,250	14,668
17:00	462,390	376,970	83,451	15,327
18:00	462,390	403,472	89,547	16,003
19:00	517,414	408,041	98,901	16,662
20:00	539,411	310,258	92,700	14,668
21:00	440,327	243,545	74,097	11,669
22:00	165,139	199,223	46,350	7,334
23:00	110,049	91,387	16,816	3,468
Total	**8,043,008**	**6,206,523**	**1,425,919**	**243,172**

After creating both input files (fleet file and the location file) the IVE model estimates the emissions of the selected pollutants by vehicle technology, type of emission (start-up and running), and by hour, it can also give the daily total emissions. For the purpose of this inventory the results were expressed in Mg/day. Results from the top-down inventory were changed and expressed also in Mg/day for a later comparison of the results from both inventories.

Finally, for a better visualization of the results a map was created using the software ArcGIS 10 to show the emission estimates for each pollutant and road.

5. Traffic road estimated emissions for the city of Querétaro, Mexico

In this chapter the results obtained from the top-down and bottom-up approaches are presented, compared, and discussed.

5.1 *Top-down vehicle emission inventory*

Starting from the results obtained using the top-down approach, after disaggregating the fuel sales data and using it as surrogate data additionally with fuel emission factors, vehicle emissions for the municipality of Querétaro for the year 2005 were calculated and the results are presented in Table 17. Emissions are in Mg/year for NOx, VOC, CO, and PM, for each type of fuel used. The annual emissions of the rest of the municipalities are shown in the Appendix A.

Table 17. Vehicle emission for the municipality of Querétaro (year 2005).

Fuel usage	Annual Emissions (Mg/year)			
	NOx	VOC	CO	PM
Gasoline vehicles	3,295.4	13,565.6	84,081.7	337.9
Diesel vehicles	9,831.8	1,479.9	5,341.6	1,379.5
LPG vehicles	1,101.6	1,540.9	4,629.5	NA
Total Municipality	**14,228.9**	**16,586.6**	**94,052.9**	**1,717.4**
Total State	**24,789.9**	**31,950.8**	**182,234.5**	**2937.1**

NA: Not Available

As it can be seen from the results shown in the Table 17, the municipality of Querétaro strongly contributes to the overall vehicle emissions in the state of Querétaro: 57% for NOx, 52% for VOC, 52% for CO, and 58% for PM. These results were expected because the city of Querétaro is the head municipality and the capital city of the state of Querétaro having not only the largest population, but also the largest vehicle fleet.

Table 17 also allows verifying that gasoline vehicles emit higher amounts of VOC and CO. This is due to the used fuel emission factors and to the number of vehicles in circulation. CO is the most emitted pollutant because it is the main product of the incomplete fuel combustion and gasoline is the main fuel used. Diesel vehicles are the most significant source of NOx and PM emissions; this was expected from the fuel composition and also because the fuel emission factors for these two pollutants are higher than the ones used for gasoline vehicles. On the other hand LPG vehicles do not contribute in a high percentage to the overall emissions of any of the pollutants because it is considered as an alternative fuel and at the moment the number of vehicles powered by LPG is very low.

Figures 14 and 15 present the vehicle emissions distribution of CO and VOC, and NOx and PM, for gasoline and diesel vehicles, respectively, for the different municipalities in the state of Querétaro.

CO and VOC vehicle emissions (Mg/year) from gasoline vehicles in the state of Querétaro

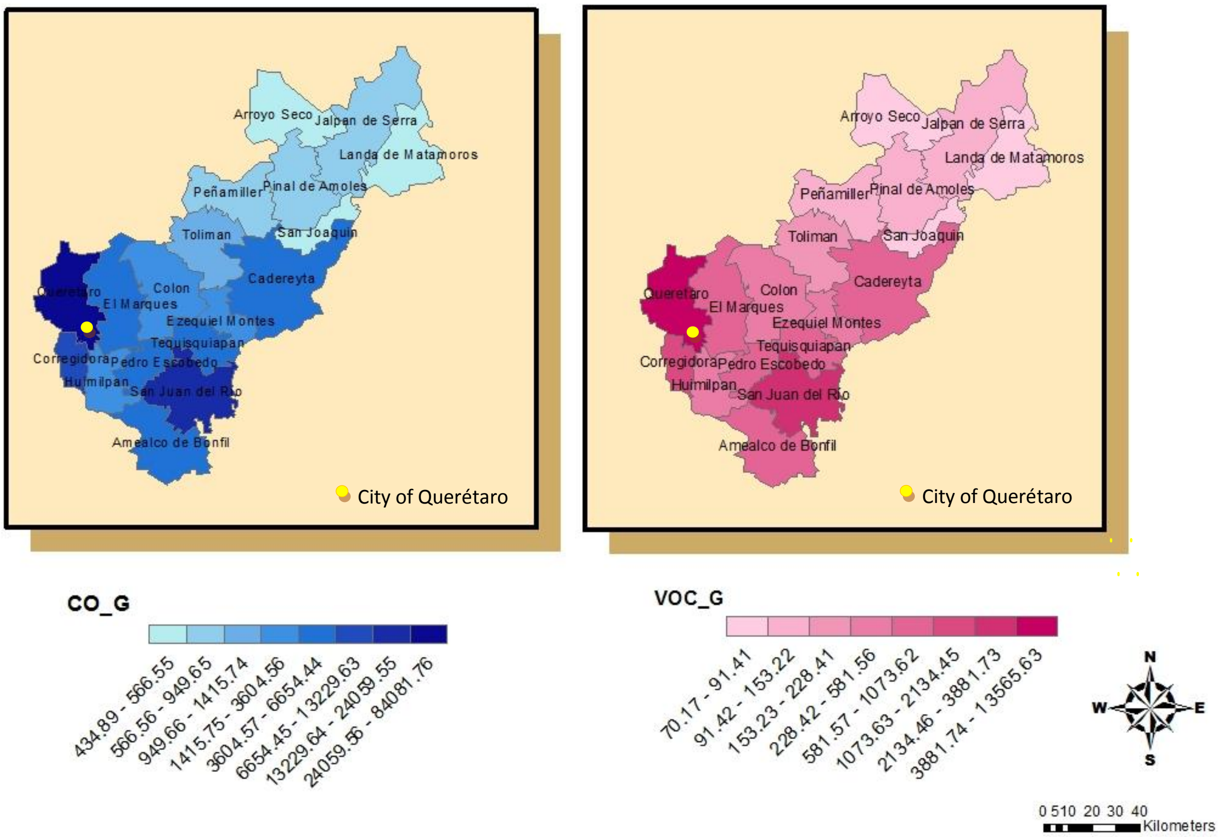

Figure 14. CO and VOC vehicles emissions (Mg/year) from gasoline vehicles in the state of Querétaro.

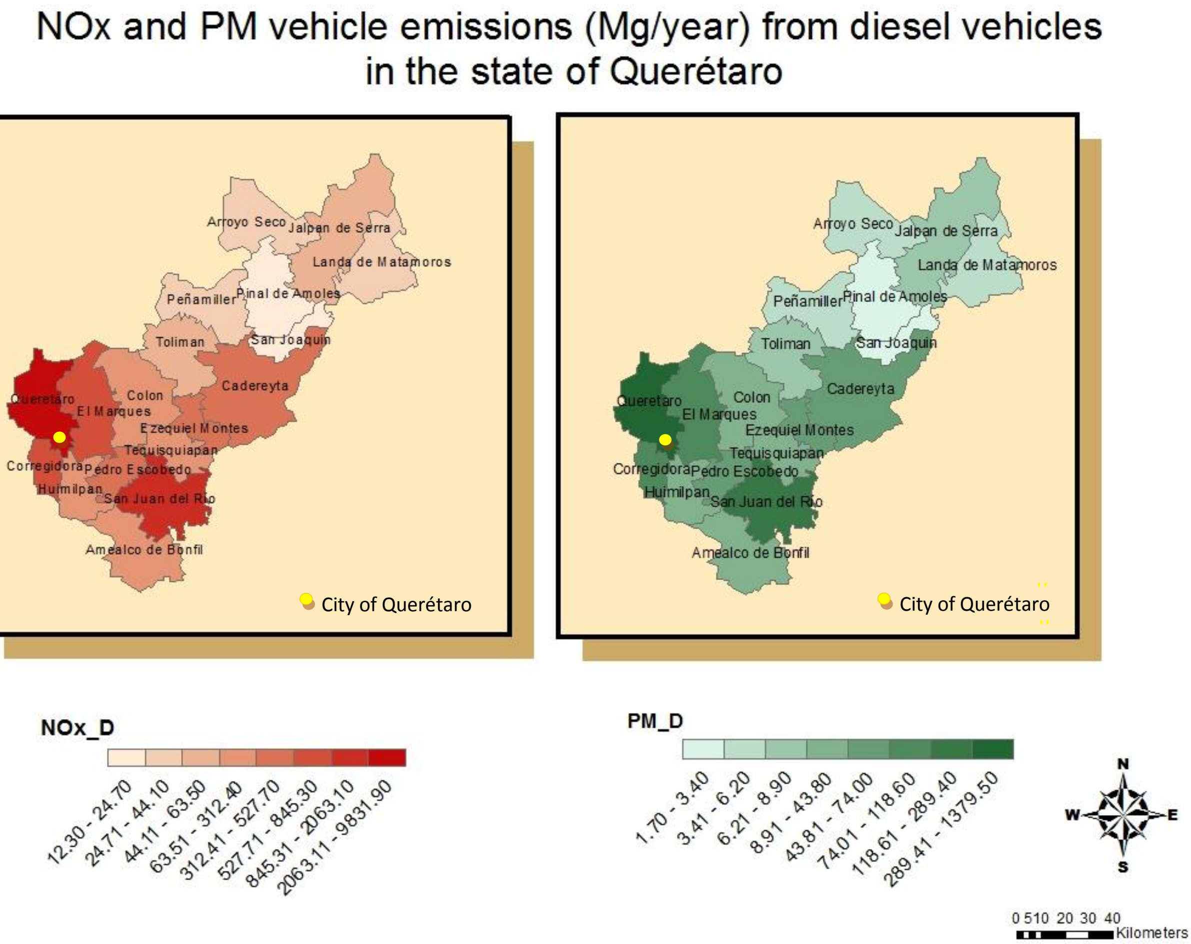

Figure 15. NOx and PM vehicle emissions (Mg/year) from diesel vehicles in the state of Querétaro.

The municipality of Querétaro presents the highest emissions of CO and VOC emitted by gasoline vehicles and of NOx and PM by diesel vehicles in the state, followed by the municipality of San Juan del Río, which is located at the southeast and is the second most populated and important municipality in the state. It is also noticed that emissions are higher in the municipalities located at the south, probably due to the higher number of highways and roads existing in this area because Querétaro allows the connection between the southern and the northern part of the country.

The total emissions for the state of Querétaro calculated using this approach was compared to the values from the National Emission Inventory 1999 for the state. The comparison is shown in Figure 16.

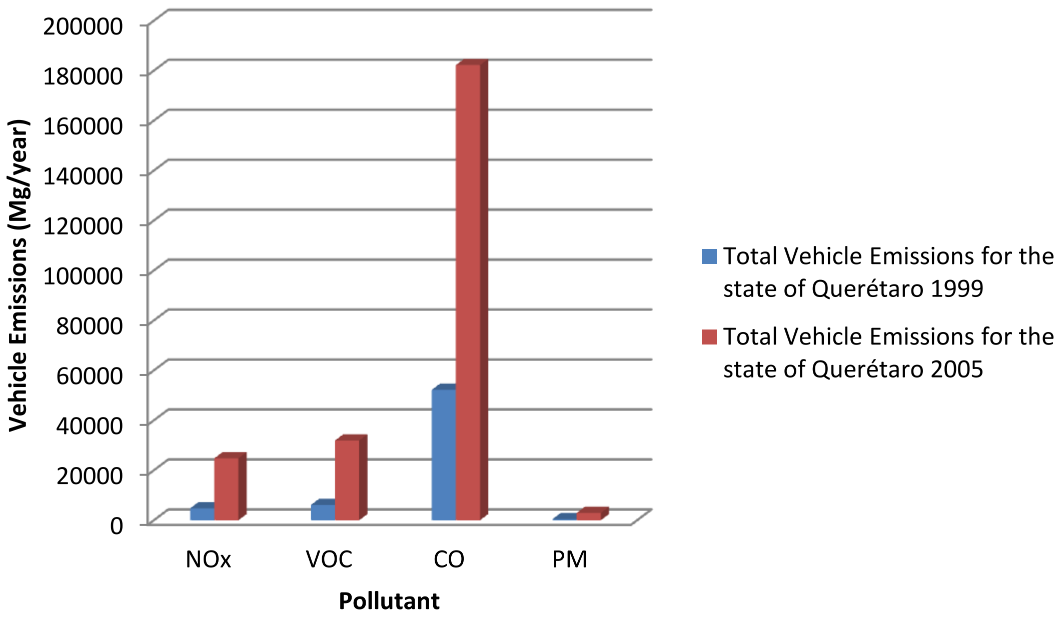

Figure 16. Comparison of total vehicle emissions for the state of Querétaro for the years 1999 and 2005.

When comparing the values of vehicle emissions obtained from this inventory to the values obtained in the 1999 NEI for the state of Querétaro it can be observed an evident increase in vehicle emissions from the year 1999 to the year 2005. This increase can be explained by the accelerated growth and development of Querétaro where, for instance, the number of vehicles duplicated along this period.

Figure 17 shows this behavior where it can be seen an increase mainly in light duty vehicles powered by gasoline and heavy duty vehicles powered by diesel.

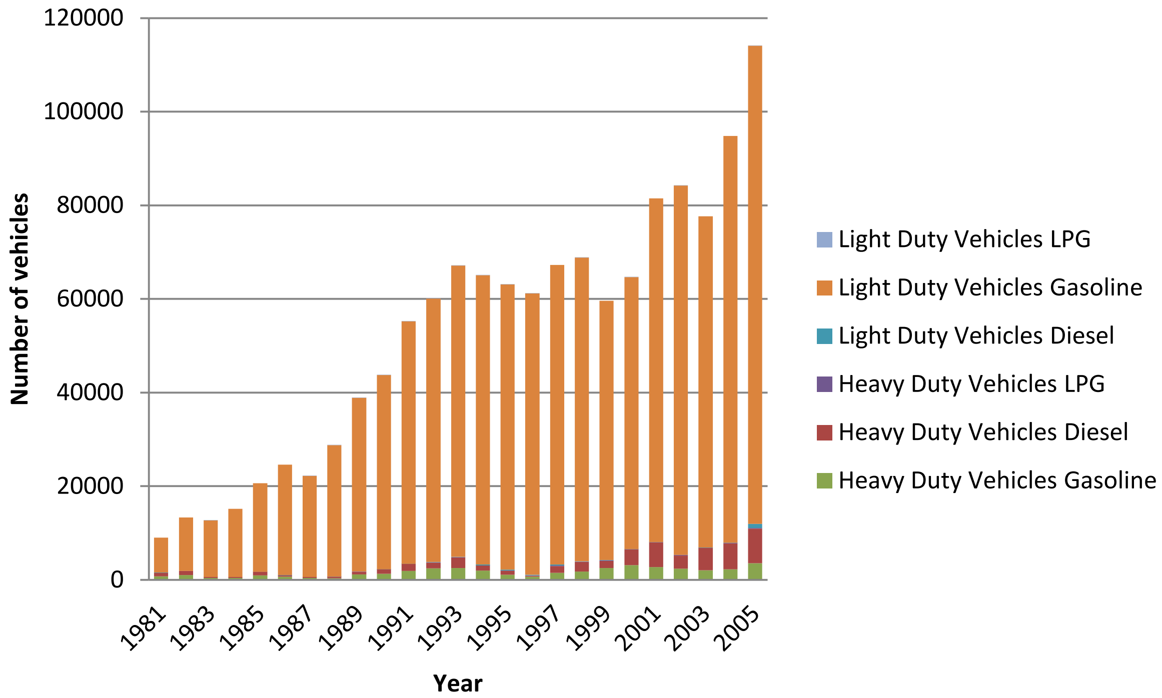

Figure 17. Evolution of the vehicle fleet distribution for the city of Querétaro (SEDESU, 2011).

Unfortunately, until now there is no official vehicle emission inventory for the year 2005 for the state of Querétaro to actually compare with the results of this study. Nevertheless, as the data used for the development of this inventory is official data from the environmental agency in Querétaro it can be expected a similar behavior of the vehicle emissions for the year 2005.

5.2 Bottom-up vehicle emission inventory

The emission results from the IVE model were divided into four groups to better understand the differences between the quantities of pollutants released for the different considered road types. Table 18 presents the total emissions of CO, VOC, NOx, and PM released during the day from passenger vehicles (gasoline), bus (gasoline and LPG), and trucks (diesel) for the different road types.

Table 18. Total vehicle emissions for each road type.

Road type	**Total vehicle emissions (Mg/day)**			
	NOx	**VOC**	**CO**	**PM**
Highway	9.77	8.58	116.45	0.44
Arterial	9.14	10.27	123.17	0.53
Second Arterial	6.94	7.58	105.31	0.36
Local	0.58	0.84	8.28	0.004
Total	**26.42**	**27.28**	**353.21**	**1.32**

From Table 18 it can be observed that CO is the most emitted pollutant in each road, followed by VOC, NOx and PM. Arterial roads are the main contributors to CO, VOC, and PM emissions. This was expected because there is an increase in vehicle activity in arterial roads, congestion also plays an important role, and starting/driving patterns also influence the total emissions. Highways have a higher contribution of emissions than second arterial roads. On the other hand, local roads are the ones that contribute the less to the total emissions from the roads considered in this inventory. It is important to mention that only eleven roads (2 highways, 3 arterial, 4 second arterial, and 2 local) were considered for the development of this bottom-up inventory, and consequently these results represent a part of the total emissions estimated for the city of Querétaro.

The contribution of CO, VOC, NOx, and PM emissions released by the different types of vehicles is shown in Figure 18.

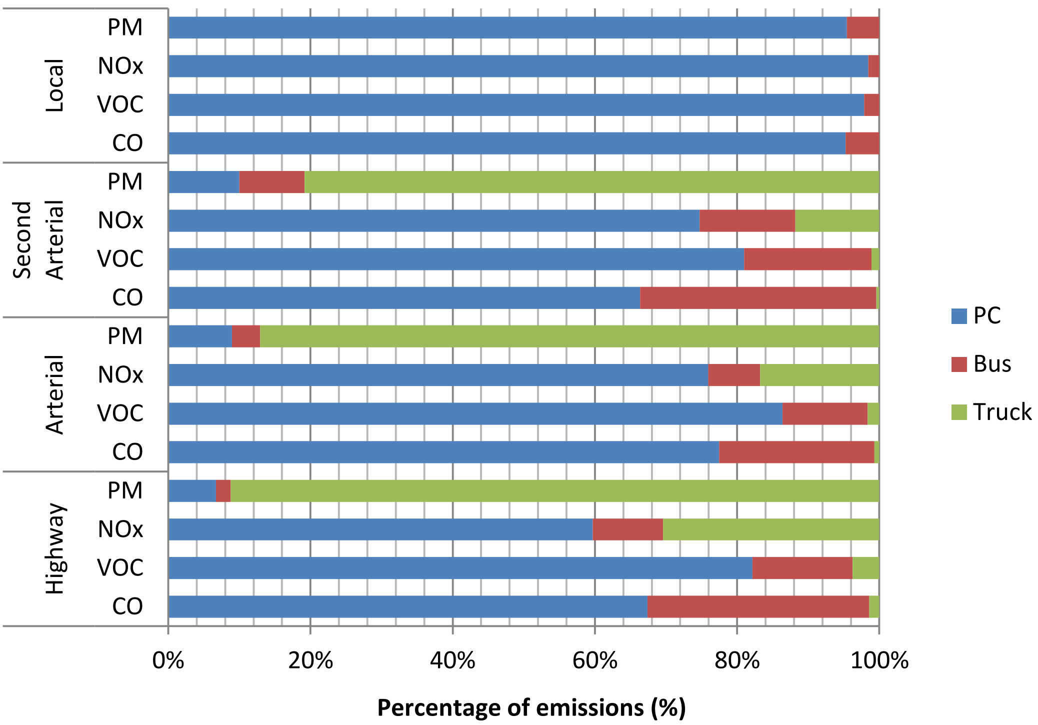

Figure 18. Contribution of CO, VOC, NOx, and PM emission per vehicle type.

It can be observed that CO, VOC, and NOx emissions are mainly released by PC vehicles and buses in highway, arterial and second arterial roads, meanwhile trucks are the main contributors of PM. Local roads are considered as residential road and only a small amount of buses and no trucks transit in this kind of roads according to the traffic counting made by CONCYTEC (2006). Therefore PC vehicles and buses are the main contributors of emissions in these roads.

Figure 19 shows the modeling results of daily CO, VOC, NOx, and PM emissions for each road type.

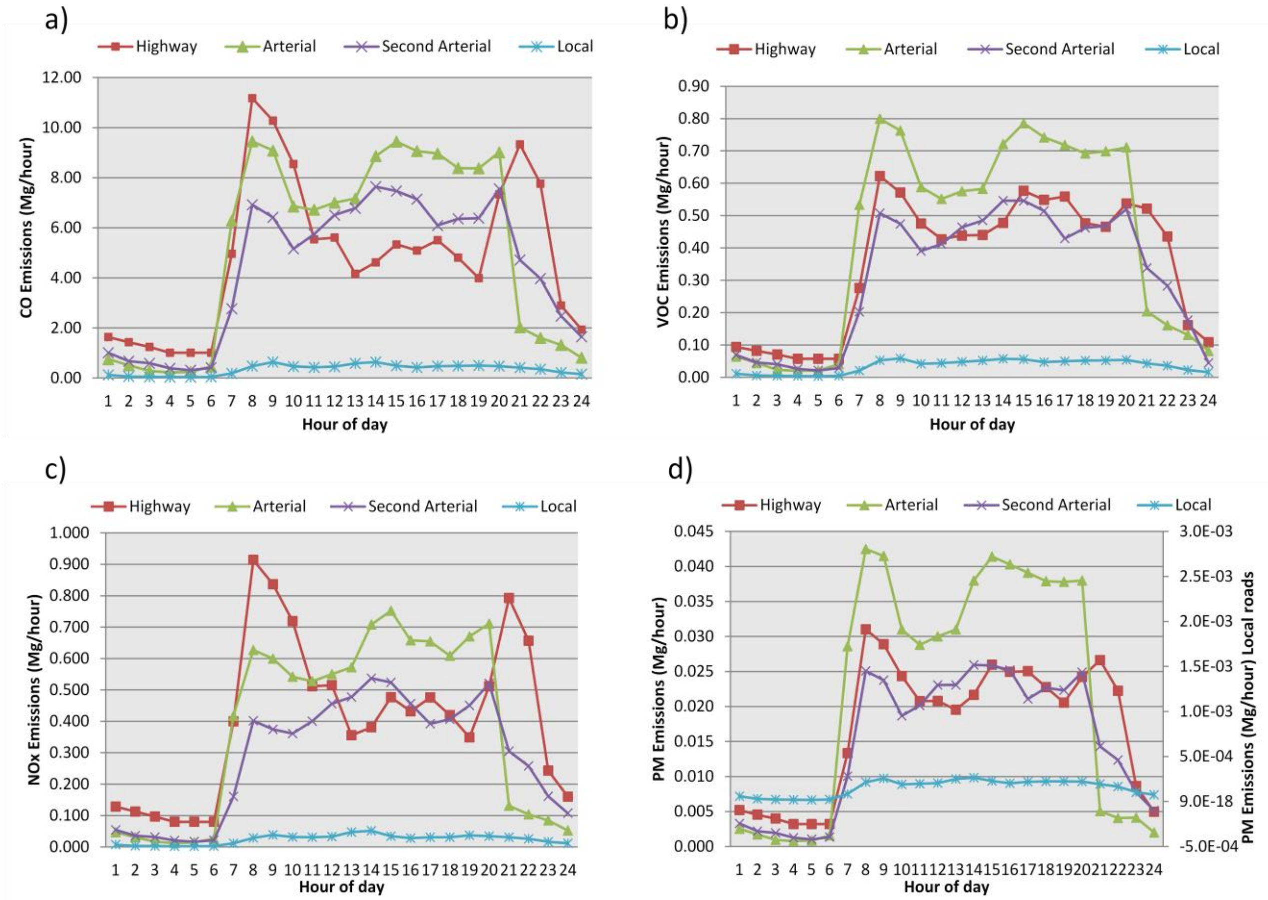

Figure 19. Daily CO (a), VOC (b), NOx (c) and PM (d) emissions.

The behavior of vehicle emissions throughout the day in the city of Querétaro depends on the type of road analyzed. For highways and second arterial roads mainly two emission peaks can be identified from the figure, the first peak occurs from 7:00 to 9:00 hours, and then there is a constant evolution throughout the day with a small increase during the afternoon, the second peak is observed from 20:00 to 21:00 hours. Arterial roads show a main peak during the morning and then a second peak during the afternoon and a constant behavior until a third peak during the evening, this can be explained due to the higher vehicle activity in these types of roads. Local roads show a constant behavior throughout the day.

Vehicle emissions released in highways represents 33% of the total emissions, while emissions in arterial roads represent 37%, second arterial roads are responsible for 27% of the emissions, and local roads for 3%. A total of 353 Mg of CO are emitted per day throughout the roads considered in this inventory. The total VOC emission is of 27.28 Mg/day including starting, running, and evaporative emissions, while total NOx emission is of 26.42 Mg/day and PM emission is of 1.32 Mg/day.

CO emissions obtained from this inventory can be compared to the total of 3900 Mg/day of CO emissions obtained by Davis et al. (2004) in Mexico City vehicle activity study using the same traffic model (IVE). It can be said that CO emissions in the city of Querétaro are considerably lower than in México City, and this can be explained considering that for the year 2005 Mexico City had 8,720,916 inhabitants and a vehicle fleet of 2,890,714 vehicles, compared to 734,139 inhabitants and 114, 170 vehicles in the city of the Querétaro during the same year (INEGI, 2006). A proportional behavior can be expected for vehicle emissions between both cities.

Table 19 presents results from other bottom-up studies developed in cities from Latin America, which show the same tendency.

Table 19. Vehicle emission studies in Latin American cities.

Location	Population (inhabitants)	Vehicle fleet (No. of vehicles)	CO Emissions (Mg/day)	Source
Lima Peru	6,321,173	825,000	3,524	Lents et al., 2004
Santiago, Chile	4,655,800	960,000	1,394	Lents et al., 2001
Sao Paulo, Brazil	10,041,500	7,653,882	8,215	Lents et al., 2004a

In order to have a spatial distribution of the emissions in Querétaro, Figure 20 and Figure 21 show the road network and the results obtained for CO and PM daily emissions.

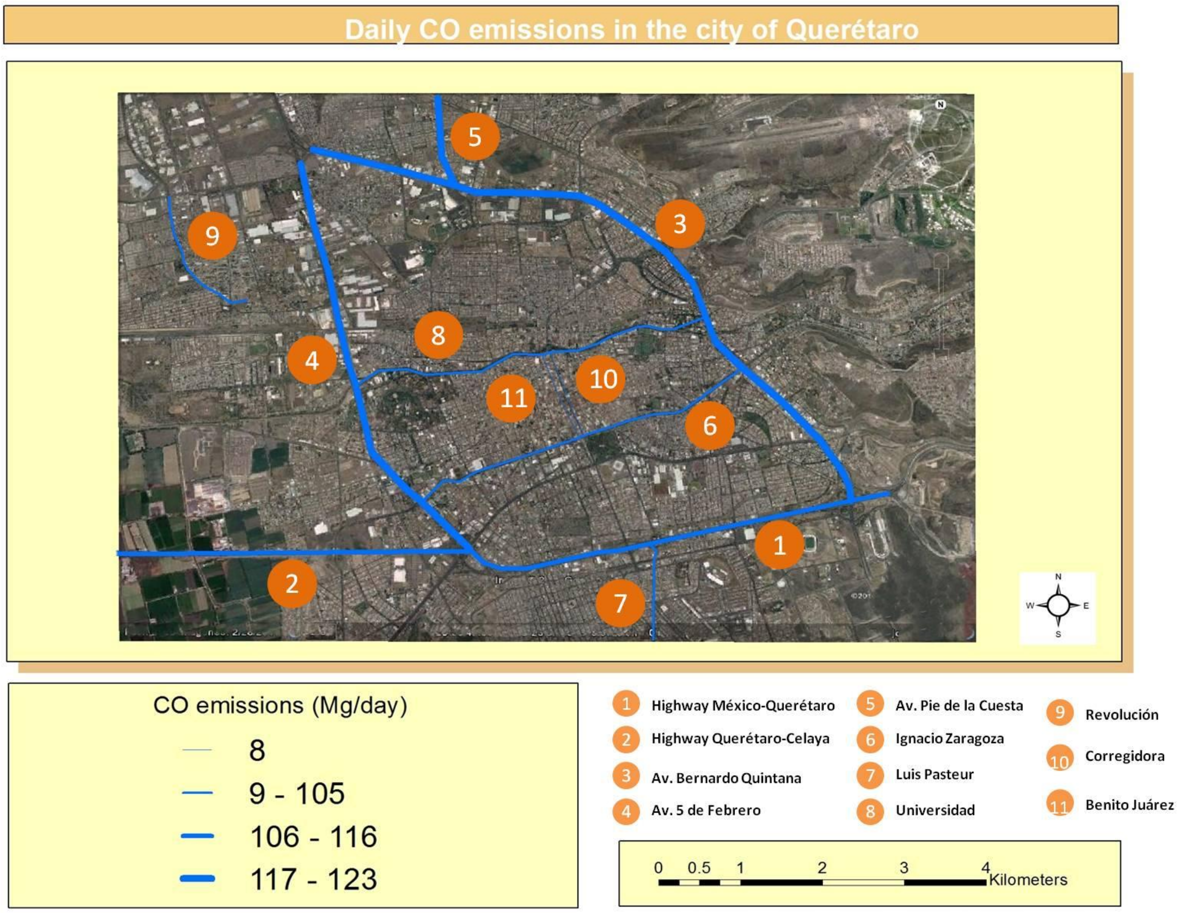

Figure 20. Daily CO emissions (Mg/day) in the city of Querétaro.

CO emissions are higher firstly in arterial roads and secondly in highways. A similar behavior was found for VOC, NOx, figures illustrating this are included in Appendix B.

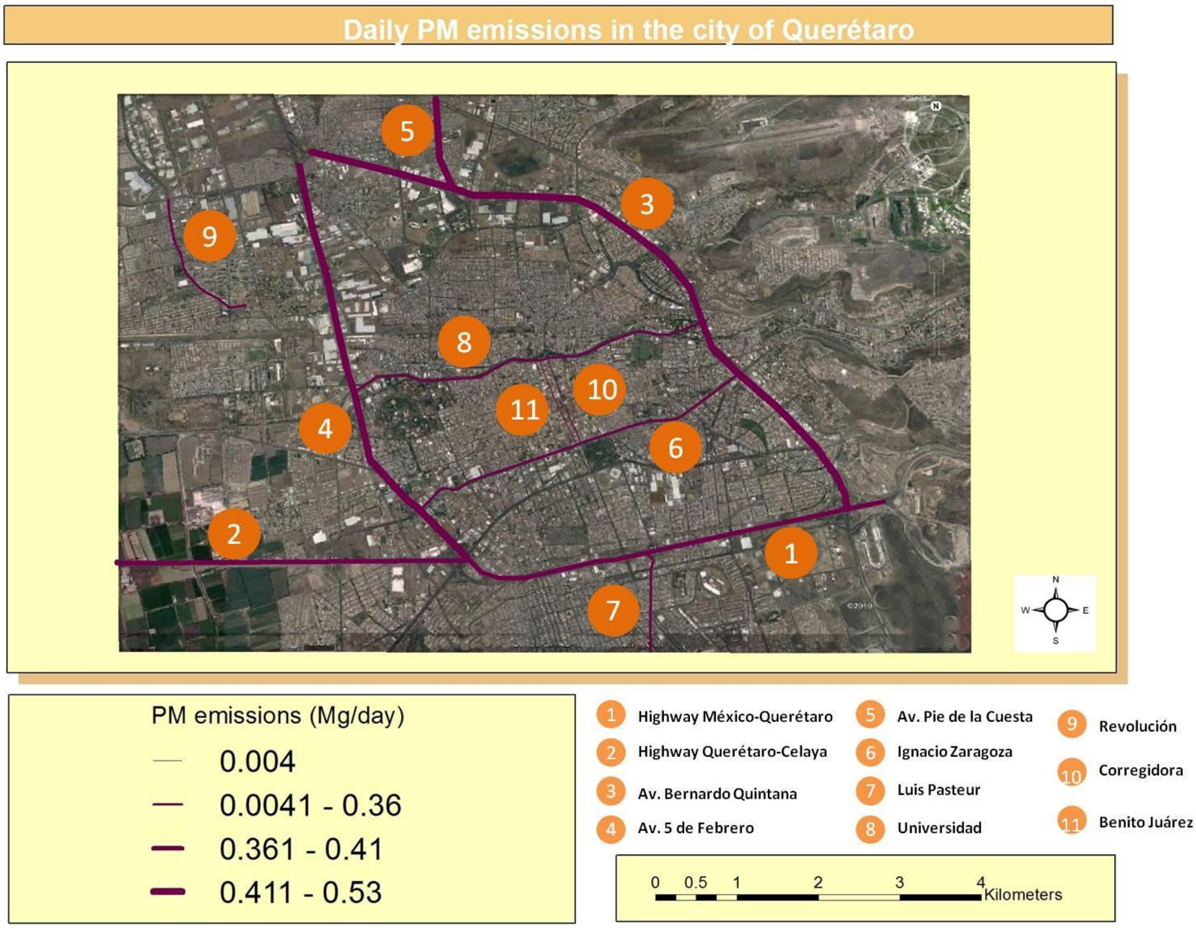

Figure 21. Daily PM emissions (Mg/day) in the city of Querétaro.

The contribution of PM emissions in arterial roads is higher than in the other roads. A higher contribution of PM emissions would be expected in highways considering that the number of trucks travelling by them is bigger than in arterial roads, nevertheless due to the higher vehicle activity in arterial roads this tendency could be explained.

5.3 Comparison of top-down and bottom-up emission inventories results

The comparison of vehicle emissions obtained from the bottom-up and top-down inventories developed in this work, was done as performed by Borrego et al. (2000). In Table 20 the results from both inventories and the differences (in %) are presented.

Table 20. Comparison of vehicle emissions obtained from bottom-up and top-down inventories.

Pollutant	Top-down inventory (Mg/day)	Bottom-up inventory (Mg/day)	Difference (%)
CO	257.68	353.68	37
VOC	45.44	27.28	-39
NOx	39.98	26.42	-32
PM	4.71	1.32	-71

The comparison of the results obtained using bottom-up and top-down approaches show a difference among the emission estimates. Management of diverse type of data influence this difference, for top-down inventory fuel sales data was used, while traffic counting for specific roads were considered for the bottom-up inventory. As presented by Borrego et al. (2000) it should be expected that at regional level vehicle emissions from top-down inventory should be higher than emissions from bottom-up inventory, whereas at a deeper level considering emission estimates for main streets the behavior should be opposite. Contrary to the expected, the results obtained for CO emissions from the bottom-up inventory are higher than the results of the top-down inventory. This can be explained taking into account some considerations.

First, the main difficulty for developing a bottom-up inventory is the specific data required for the traffic model. Second, the emissions estimates vary from one traffic model to another due to the emission factors used for each methodology, vehicle fleet distribution and technologies, and correction factors.

The results obtained in this work from the bottom-up inventory (using IVE model) show that CO emission are 37% higher than the ones resulting from the top-down inventory, while VOC, NOx, and PM are lower (-39%, -32%, and -71% respectively). Similar to this, the results obtained in the study made by Osses (2005) comparing two bottom-up vehicle emission inventories developed in Santiago, Chile using IVE and MODEM traffic emission models show that CO emissions obtained by IVE model are 51% higher, while NOx are -29%, VOC -4%, and PM -45% lower than the results obtained using MODEM. From these results it can be observed that in both cases IVE model is overestimating CO emissions. This can be due to the default parameters used by the model, bringing as consequence a gap between emissions estimates obtained by the bottom-up and the top-down inventories. In order to have a better understanding of this difference further analysis of the default parameters used by IVE model should be considered. Also it is important to continue developing studies to obtain local emission and correction factors and to include more traffic measurements in the city of Querétaro in order to avoid the use of default parameters and to reduce uncertainties.

6. Conclusion

A vehicle emission inventory for the city of Querétaro was developed using top-down and bottom-up methodologies. Vehicle emissions from top-down inventory for the state of Querétaro show an increase compared to vehicle emissions reported in the 1999 Mexican National Emission Inventory due to the accelerated growth and development of the city of Querétaro. Also it is noticed that emissions from the municipalities located in the south of the state of Querétaro are higher than in the rest of the municipalities, probably due to the higher number of highways and roads existing in this area.

Vehicle emissions from bottom-up inventory using IVE model and considering different type of roads show that CO is the most emitted pollutant in each road followed by VOC, NOx and PM. Arterial roads are the main contributors of these emission due to the intense vehicle activity, followed by highways, second arterial roads, and local roads.

Results from the top-down and bottom-up vehicle emission inventories were compared finding differences among the results obtained with the two different methodologies. The comparison of the two methodologies shows that CO emissions from bottom-up inventory are higher than CO emissions from top-down inventory, contrasting with the comparison made by Borrego et al (2000). One of the possible factors that influence this behavior is addressed to the traffic emission model used in the bottom-up inventory. The default parameters used by IVE model might cause an overestimation of CO emissions, for this reason local emission factors and traffic measurements are strongly recommended to be used in IVE model in order to improve the emission estimation.

The results of this thesis can be used as background for developing future studies in the city of Querétaro. However, the consideration of using available local data is of relevance importance in order to avoid uncertainties and have more reliable results.

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URL 6: http://sie.energia.gob.mx/sie/bdiController

APPENDIX A

Annual vehicle emissions for all the municipalities in the state of Querétaro

Table A.1 and A.2 show the annual vehicle emissions for each municipality in the state of Querétaro using the top-down methodology.

Table A.1 CO and VOC annual emissions by municipality.

No.	Municipality	CO (Mg/year)			VOC (Mg/year)		
		Gasoline	Diesel	LPG	Gasoline	Diesel	LPG
1	**Amealco**	5083	169	155	820	47	51
2	**Arroyo Seco**	438	16	31	70	4	10
3	**Cadereyta**	5618	241	62	906	66	20
4	**Colón**	3604	125	31	581	34	10
5	**Corregidora**	13229	459	590	2134	127	196
6	**El Marqués**	6654	455	310	1073	126	103
7	**Ezequiel Montes**	3575	286	62	576	79	20
8	**Huimilpan**	2795	100	31	450	27	10
9	**Jalpan de Serra**	940	34	93	151	9	31
10	**Landa de Matamoros**	434	23	0	70	6	0
11	**Pedro Escobedo**	5012	230	93	808	63	31
12	**Peñamiller**	949	18	0	153	5	0
13	**Pinal de amoles**	728	6	0	117	2	0
14	**Querétaro**	84081	5341	4629	13565	1479	1540
15	**San Joaquín**	566	13	0	91	3	0
16	**San Juan del Río**	24059	1120	2641	3881	310	879
17	**Tequisquiapan**	24059	138	186	857	38	62
18	**Toliman**	1415	29	0	228	8	0

Table A.2 NOx and PM annual emissions by municipality.

No.	Municipality	NOx (Mg/year)			PM (Mg/year)	
		Gasoline	Diesel	LPG	Gasoline	Diesel
1	**Amealco**	199	312	36	20	43
2	**Arroyo Seco**	17	30	7	2	4
3	**Cadereyta**	220	444	14	22	62
4	**Colón**	141	231	7	14	32
5	**Corregidora**	518	845	140	53	118
6	**El Marqués**	260	838	73	26	117
7	**Ezequiel Montes**	140	527	14	14	74
8	**Huimilpan**	109	185	7	11	26
9	**Jalpan de Serra**	36	63	22	3	8
10	**Landa de Matamoros**	17	44	0	2	6
11	**Pedro Escobedo**	196	423	22	20	59
12	**Peñamiller**	37	33	0	3	4
13	**Pinal de amoles**	28	12	0	3	2
14	**Querétaro**	3295	9831	1101	337	1379
15	**San Joaquín**	22	24	0	2	3
16	**San Juan del Río**	942	2063	628	96	289
17	**Tequisquiapan**	208	254	44	21	35
18	**Toliman**	55	54	0	5	7

APPENDIX B

Daily vehicle emissions for the city of Querétaro

Figures B.1 and B.2 show the daily VOC and NOx emissions in the main streets of the city of Querétaro using bottom-up methodology.

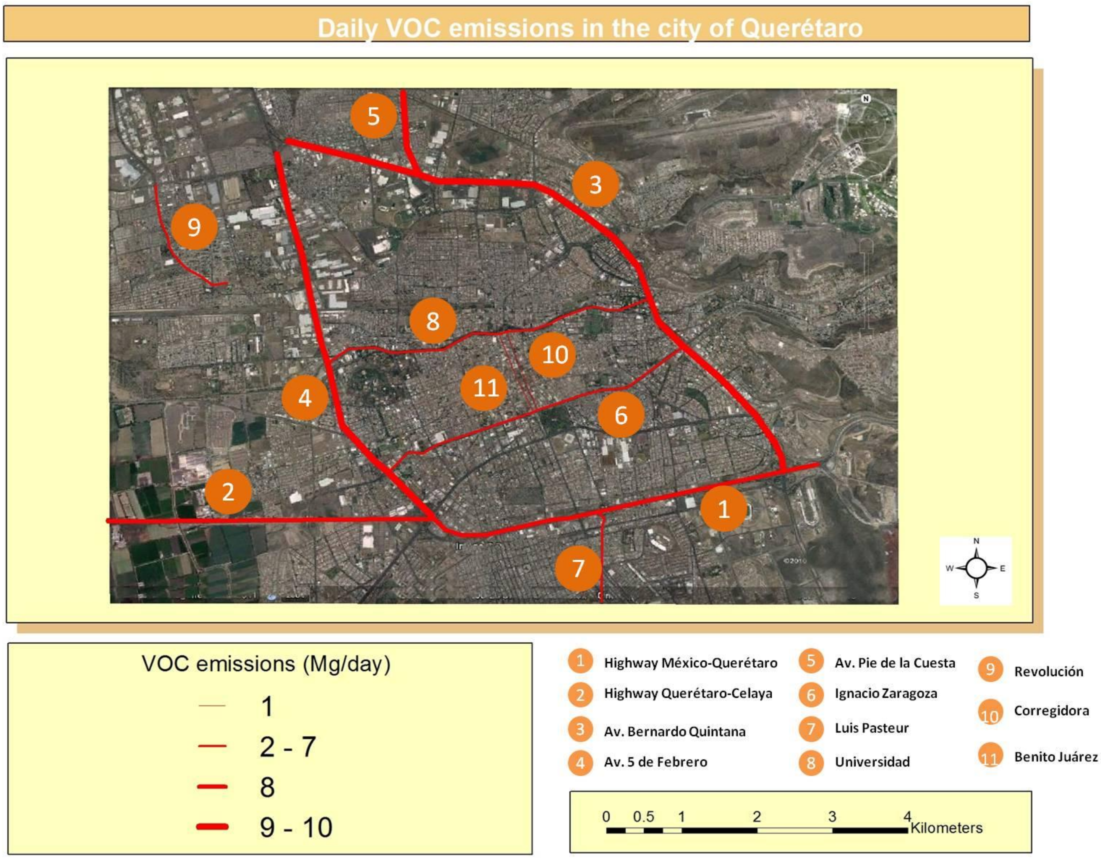

Figure B.1 Daily VOC emissions (Mg/day) in the city of Querétaro.

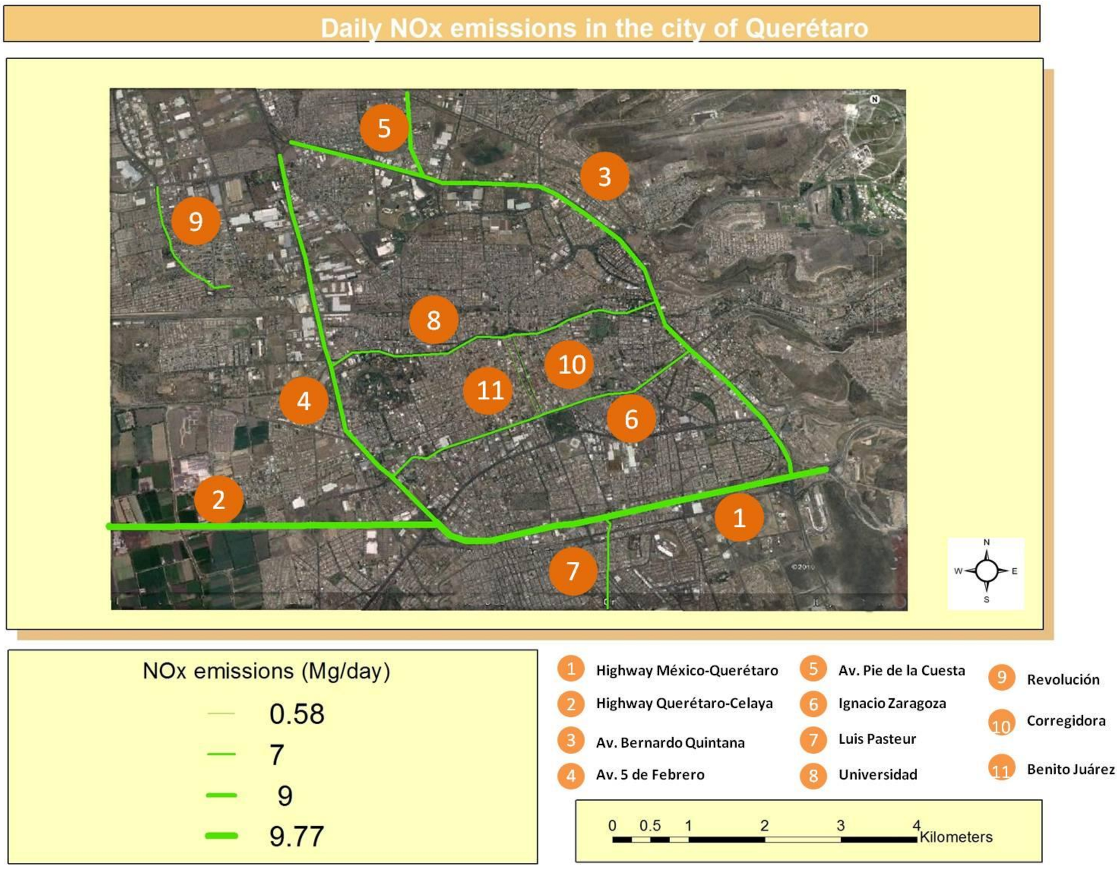

Figure B.2 Daily NOx emissions (Mg/day) in the city of Querétaro.